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Planning as a Metabolic Intervention

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Planning as a Metabolic Intervention

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Abstract

Planning as a Metabolic Intervention

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Human society relies heavily on flows of natural resources though a process called social metabolism. Growing populations and material throughput have become an ominous pattern as the negative feedbacks stemming from industrialized societies push the limits of the planetary life-support system. As the home for the majority of people and the demand-driver for material consumption, the city is a strategic point of intervention. City planners have historically, though perhaps unintentionally, shaped the social metabolism of cities. To address the rift between cities and nature, this paper seeks to refine and improve upon the existing planning approaches to guiding social metabolism. A review of social metabolism studies informs how existing data and analysis techniques can be integrated into comprehensive planning. A prototype of this methodology is presented for the water metabolism of Austin TX, demonstrating the promise of integrated metabolic planning.

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Chapter 1: Introduction

To support themselves, humans consume resources though a process called *social metabolism,* or the biophysical exchanges between society and nature (Molina and Toledo 2014). Most of these resources originate in natural system where production and regulation of natural resources occurs not through human initiative but through otherwise naturally occurring biophysical processes called *ecosystem services*. Before these resources arrive at consumers in cities, they must first be appropriated (ie. extracted or harvested) from the biosphere. Similarly, mineral resources are mined from the Earth's crust or lithosphere. Appropriation processes often yield negative feedbacks on biospheric production. If too much is taken, the resource base can become exhausted. Appropriation can also damage production through land-use changes (eg. deforestation) and/or pollution (eg. mining runoff).

Within the human system, natural resources are often circulated, transformed, and consumed. Throughout this process, resources excrete as waste that can be re-used as a natural resource (eg. grey water), recycled back to the biosphere (eg. compost), polluted into the biosphere (eg. dumping), or dissipated. Like pollution from appropriation, that generated by waste can also create negative feedbacks in the biosphere.

Contrary to common perception, natural resources are not "used", rather they flow through natural and human systems and vice versa, creating a perpetual resource cycle. Dissipation, which occurs when useable resources become inaccessible due to sharp increases in entropy or because of toxic contamination, disrupts this cycle. To study social metabolism is to seek an understanding of how life-giving resources flow through cities and impact production originating in natural systems.

1.1 The Acceleration of Metabolism

Social metabolism varies throughout the planet but population growth and industrialization are two consistent patterns that accelerate and amplify social metabolism; *industrialization* can be understood as a specific pattern of affluence (A) and technology (T) that combine with population (P) to form a relationship between human consumption and impacts (I) on the environment (Chertow, 2000). Of course, population and industrialization are themselves related. Shifting from an agrarian to an industrial society "is inherently linked first to population growth and later to a surge in material and energy use per capita" (Krausmann et al 2008). The increase in metabolism is driven by intensive industrial production systems (including agriculture), large infrastructures and physical stocks, high mobility of goods and people, and a high material standard of living (Krausmann et al 2008). Despite major improvements in energy and material efficiency, there was an eight-fold increase in total energy and resource flows through the 20th century (Krausmann et al 2009).

Although this measure only stands as a proxy for environmental degradation, human activity did significantly impact the biosphere during the 20th century (McNeill 2001). Some have developed indicators like Human Appropriation of Net Primary Productivity (HANPP) to assess these impacts on the biosphere. An average of HANPP studies indicates approximately one-quarter of all *primary productivity*, or photosynthetic resources, is either harvested by humans or have been displaced by human-induced land-use change, limiting the trophic energy available for natural systems (Haberl et al 2014). Others have identified planetary boundaries conditions that, if surpassed, would yield environmental deterioration large enough to damage the carrying capacity of the Earth. Of the nine boundaries identified, three have been surpassed – climate change, biodiversity loss, and nitrogen cycling (Rockström et al 2009). Given demographic and economic forecasts, a similar and ominous trend will continue through the 21st century as material and energy use will likely triple by 2050 (Krausmann et al 2008).

The shift from agrarian to an industrial society does correlate with a shift from low to high societal throughput, but one that is based on continual technological innovation. However, the assumption of unlimited technological replacement is flawed – the production of oxygen, water, and photo-synthetic resources, namely food and fibers, all cannot be substituted and are dependent on the biosphere and ecosystem services (Ayers 2009). Therefore, social metabolism must reach a balance with the biosphere.

Historically, this balance has not existed except perhaps within hunter-gatherer societies. Agrarian societies, like those found in Medieval Europe, were based on solar energy accrued in the form of biomass. Although biomass is a renewable resource, pressures from growing populations lead to degradation of the resource base, specifically the exhaustion of agricultural soils (Krausmann et al 2008). Observing the process of soil degradation amid the acceleration of social metabolism due to industrialization, Marx warned about how systems of production created an "irreparable rift in the interdependent process of social metabolism" (Foster 1999, Marx 1981). Soil degradation may have been the most tangible pattern of the *metabolic rift* in agrarian societies, but the rift process can be and has been expanded. The transition to a fossil fuel-based energy system has (temporarily) solved problems associated with the agrarian rift, but other, less conspicuous conflicts have emerged. This is partly because human-to-nature coupling is, unlike agrarian societies, no longer spatially constrained by the energy system (Clark 1967). Moreover, human production now requires as inputs a plethora of exhaustible resources that, like phosphorous (Gilbert 2009), are highly specialized and disconnected from mainstream consciousness. When combined these factors create a spatial and cultural disconnect between humans and nature that persists despite significant social and technological progress. The rift remains, even if the language has changed; contemporary scholars (Sassen and Dotan 2011) describe the mode of human transaction with the biosphere as "rupture". Whatever the term used, the process is unchanged – social metabolism undermines its own foundation through exhaustion, pollution, and dissipation of the resource base. Therefore, the modern industrial paradigm cannot be considered a viable stable-state (Sieferle 1997 cited in Krausmann et al 2008). To address this issue, I propose that planning – a field that traditionally, though informally, directs and shapes social metabolism – strategically intervenes to create a viable long-term social metabolism.

1.2 A Strategic Scale

Planning is not the only field capable of metabolic intervention, but it is one of the most important because it plays a major role in guiding and shaping cities. As of 2014, 54% of the global population live in cities and by 2050 the proportion may be as high as two-thirds (United Nations 2014). And because industrial consumer affluence tends to be higher for urban populations, the vast majority of resource use and pollution occurs because of production and consumption in cities. For this reason, and because "questions of power, poverty and inequality, ideology and cultural preferences" are inextricably linked to consumption-based environmental deterioration, "the city becomes a strategic space for the direct and brutal confrontation between forces that are enormously destructive to the environment and increasingly acute needs for environmental viability" (Sassen 2010).

It must be mentioned that, through "teleconnection with remote sources of food, water, fuel, and materials" (Decker et al 2000), the geography of urban consumption extends beyond the borders of any city. This indirect environmental degradation most certainly exceeds that which falls within city boundaries. Emerging networks of cities are gaining momentum in their ability to tackle global issues such as climate change, but addressing these indirect effects of consumption will require action beyond the governance capacity of any single city. But if people do not yet demand balance in their direct and more visible biospheric-interaction, there can be little hope for more comprehensive change.

Addressing the direct metabolic rift of cities is therefore a crucial and strategic step towards closing the global rift. Unfortunately, present industrial cities do not become more ecologically efficient as they increase in size (Decker et al 2000, Bettencourt et al 2007); however, the economic scale, population density, and dense communication networks within cities mean there is significant opportunity to for investment, innovation, and increased resource efficiency, especially through re-use. There is no reason the urban advantages of dense interactions espoused by Jane Jacobs in *The Economy of Cities* (1969) can't also apply to a sort of "environmental entrepreneurship". To facilitate this, cities must establish a "sustainable consumption logic" through land-use and zoning; regulation of development; transport, water, and waste planning; and environmentally conscious budgeting and procurement (Sassen 2010). Planners are an essential component of establishing this new logic, and must therefore leverage social metabolic data "to design the urban metabolism of sustainable cities" (Kennedy et al, 2009).

1.3 Research Objectives

To be clear, social metabolism is similar to but different from social-ecological research. Social metabolism focusses on the biophysical flows that sustain humanity and subsequently impact natural systems. Social-ecological research is broader and further includes socioeconomic and cultural drivers, patterns, and processes (Grimm et al 2000) and the resulting organizational, spatial, and temporal human-nature coupling (Liu et al 2007). Therefore, social metabolism can be considered a niche within social-ecological research. Social metabolism accepts the fundamental socio-ecological assumption that socioeconomic systems and the biosphere are integrated systems that affect and are affected by one other. Given this assumption, this paper seeks to address the following research questions:

- How has social metabolism intersected with traditional planning methodologies?
- How can social metabolism be integrated into a new comprehensive planning methodology?
- How has planning shaped and guided the flows of water in Austin TX?

- What stand as the greatest opportunities to re-design Austin's metabolism to ensure that city consumption does not undermine the future natural productivity?

This paper begins by describing a conceptual model for how social metabolism affects human and natural systems. Next, a literature review will first elaborate the evolution of social metabolism as theory and methodology and second, examine how the field of planning has been historically interwoven with social metabolism. After, an example social metabolic planning study analyzes the water metabolism in Austin. A discussion then analyzes the metabolic study, highlighting successes and opportunities in Austin, TX.

Chapter 2: Social Metabolism – Conceptual Model

The flow of life-giving resources in a natural ecosystem, as discussed in biology and ecology, is a complex biochemical process. So it comes as no surprise that the flow of energetic and material resources through social-ecological systems, or social metabolism, is similarly complex (Figure 1). Social metabolism is a closed system except for the energy received from the sun. Solar energy is the primary source of nearly all energy, including fossil energy, and only a fraction of what comes into the planet is retained. The closed social metabolic system is comprised of five spheres: the atmosphere, lithosphere, hydrosphere, biosphere, and anthroposphere (Table 1).

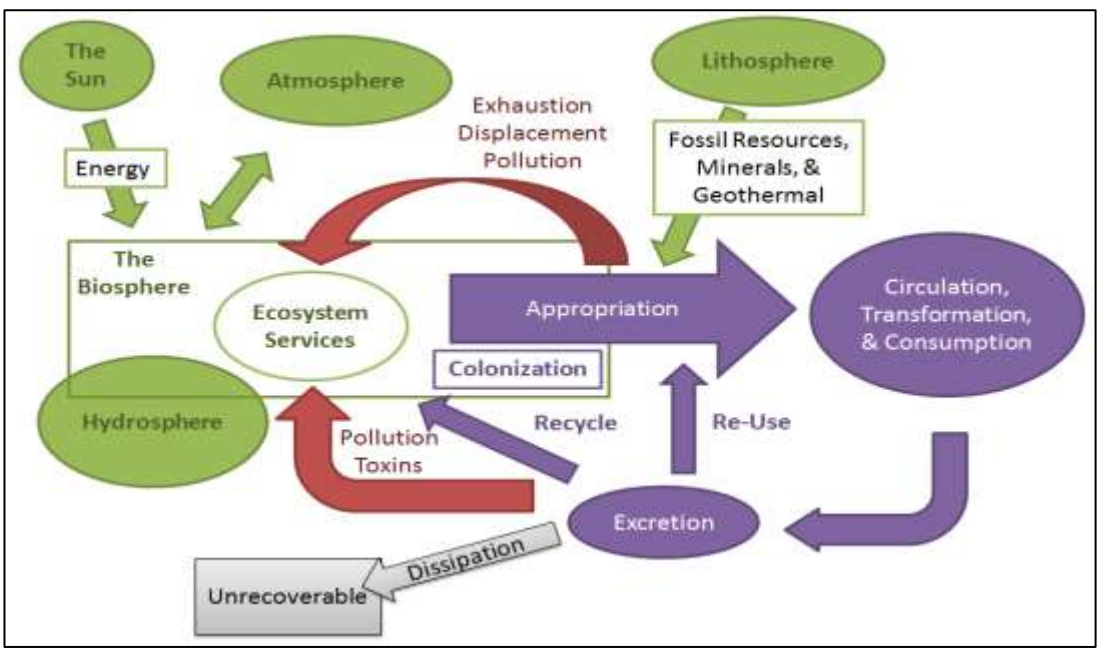

Figure 1: The Social Metabolism Life-Cycle.[1]

[1] Social Metabolism is the analysis of flows from Nature (Green) through the Anthroposphere (Purple) and back into natural systems. Negative Feedbacks (Red) occur during the two modes of social ecological

Sphere	Definition	Function in Social Metabolism
Atmosphere	the layer of gases surrounding the planet, including the section closest to the ground (the troposphere)	supplies plant and animal respiration with carbon dioxide and oxygen; assimilates and distributes airborne pollutants; reservoir of nitrogen for synthetic chemicals
Lithosphere	the layer of rock closes beneath the surface, including the crust	stores fossil resources - energy and water- created through geological processes and mineral deposits
Hydrosphere	Surface water, oceans, ground water, and rainfall	Supplies water to the biosphere and anthroposphere; assimilates pollution and waste; provides aquatic habitat
Biosphere	biomass and living organisms and substrates (soil)	leverages ecosystem services for primary productivity (food and fibers) and provides habitat for game animals; microbial processes including nutrient recycling
Anthroposphere	the mass accumulated through socioeconomic and technological processes	infrastructure, buildings, transportation, manufacturing and goods, industrial chemicals, etc.

Table 1: The 5 spheres of Social Metabolism.

2.1 Ecosystem Goods and Services - an Integrative Concept

The conceptualization of the relationship between nature and society is ever evolving and has been heavily debated at least since Pliny the Elder (23 – 79AD). A precise definition of this relationship is not the focus of this paper, nor is it necessary since the focus of social metabolism is on empirical flows and environmental impacts, not subjective interpretations. Some prefer not to separate nature and society, but for the sake of clarity, the terms "human" and "social" will be used to describe the Anthroposphere while "natural" describes the other four Spheres. Of course, there are many socio-ecological interactions where social and natural systems overlap, particularly during the two modes of exchange – appropriation and excretion (Molina and Toledo

exchange and Dissipation (Grey) occurs when resources leave the resource loop due to increases in entropy. Adapted from Molina and Toledo (2014).

2014). It is during these processes that ecosystem services emerge as a crucial conceptual tool for understanding how natural resources enter and leave the socio-metabolic life-cycle.

The ecosystem service concept clarifies how humans are directly or indirectly dependent on natural systems and is especially useful to comprehend interactions that, despite their necessity for life, are not fully included in traditional economics (Constanza 1997). Leveraging and classifying the ecosystem service concept depends on the relevant political context and policy requirements (Fisher er al. 2009), but the Millennium Ecosystem Assessment (MA) (2005) provides four broadly applicable categories of ecosystem services: supporting, provisioning, regulating, and cultural (Figure 2).

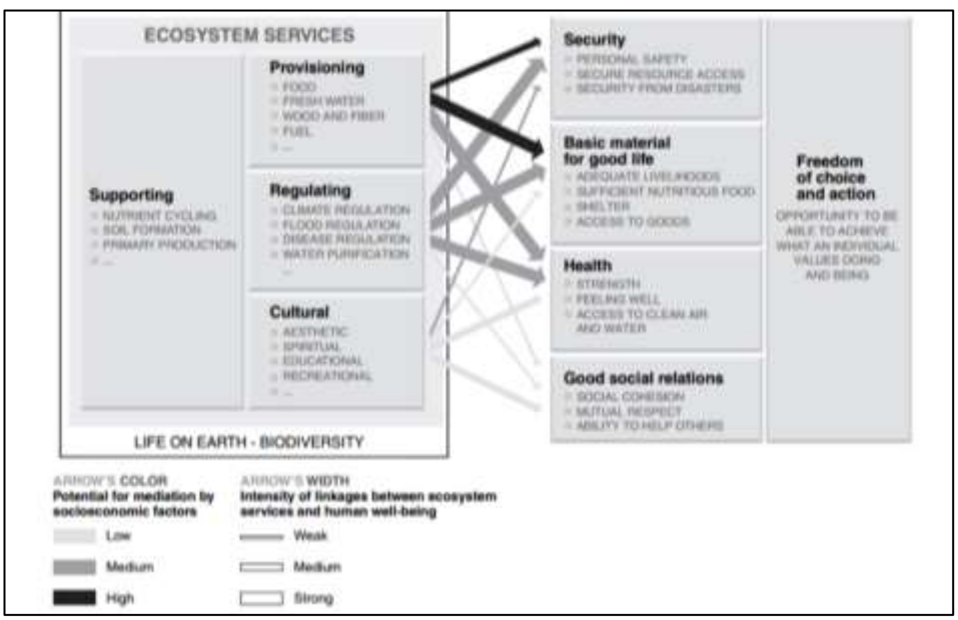

Figure 2: Ecosystem Services by Type with Relationship to Human Well-Being[2]

[2] Source: Millennium Ecosystem Assessment (2005)

The exclusion of many biophysical processes from economics has led to the replacement of some ecosystem services with energy-intensive infrastructure (Decker er al 2000). Ironically, this substitution can lead to increased costs if one uses more inclusive economic valuation techniques. The successful incorporation of ecosystem services into public decision making can lead to large cost savings. For example, New York City (NYC) opted to conserve and expand ecosystems services in upstate New York instead of building a new filtration plant. With an estimated cost of $6 billion and an annual operating budget of $300 million, constructing the plant would have been a significantly more expensive alternative (Pires 2004). The oft cited NYC example, along with similar projects implemented by other cities, demonstrates how vast consumption within a city indirectly impacts natural systems well beyond urban boundaries. However, ecosystem services also have direct impacts within cities. Street trees, lawns and parks, urban forests, wetlands, lakes, and streams provide air filtration, micro climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational and cultural values (Boland and Hunhammar 1999). Whether direct or indirect, ecosystem services produce the natural resource base that supplies social metabolic appropriation – the entry point for the Anthroposphere.

2.2 APPROPRIATION AND NEGATIVE FEEDBACKS

The distinction between human and naturals systems becomes blurred during the Appropriation and Excretion processes. In simple terms, *appropriation* is when humans "take" from nature while *excretion* is when human "give" to nature. There are often negative feedbacks associated with both the "give" and the "take" (excretion will be discussed further in a subsequent section).

Appropriation is a diverse phenomenon with myriad of disturbance outcomes. Hunting and gathering does not fundamentally alter ecosystem structure if consumption rates align with ecological production. Conversely, c*olonization* occurs when humans re-structure ecosystems in an effort to appropriate higher rates of ecological production; farming, animal husbandry, forestry, and dams are some examples. Colonization involves the suppression of elements of pre-existing ecosystems while amplifying others. For example, control over genetics and breeding, hydrological intervention, and other management activities are all tools of colonization (Fischer-Kowalski and Haber 1998).

Despite significant human intervention, colonization remains deeply dependent on ecosystem services, as are hydrological and atmospheric extraction processes. Appropriation that leverages ongoing, reproducing ecosystem services is considered *renewable*. Non-renewable appropriation takes resources, mostly from the Lithosphere, that are not readily replenished. Despite the fact that fossil energy and water resources are originally byproducts of ecosystem services, their current state is the result of geological processes with substantial temporal requirements. Thus, fossil resources are considered non-renewable because they are produced at an extremely slow rate. Mineral resources, such as precious metals, are similarly non-renewable because they are the result of planetary processes that cannot be viably reproduced. Appropriation of both renewable and non-renewable resources provides the energy and materials needed to sustain society, but it can also negatively impact the production of natural resources.

Negative feedbacks occur when the process of appropriation includes outcomes that reduce nature's capacity to produce future resources. Both renewable and non-renewable resources can be exploited until *exhaustion*; non-renewables dwindle when continually extracted and renewables eventually become exhausted if the rate of appropriation exceeds biological production. Human land-use, including urban settlements, *displaces* ecosystem services though green infrastructure is an emerging strategy for mitigating urban displacement. Colonization is another form of displacement because, despite the continuation of ecological production, colonized primary productivity is often lower than that yielded by the displaced ecosystems (Fischer-Kowalski and Haber 1998). It is possible to reverse the displacement process, but deterioration of ecosystem structure can inhibit a full recovery. Appropriation also yields *pollution*, which is residual energy or materials that are neither incorporated into the anthroposphere nor reintegrated back into natural ecosystem production. Pollution inhibits local and global ecosystem services by altering ambient ecosystem conditions and, as will be discussed further in Section 2.4, through contamination with chemicals foreign to natural biochemical processes. Appropriation necessarily interrupts natural processes and structures, but the impact can be minimized – adaptive management is one such approach (Molina and Toledo 2014). Appropriation plays a crucial role in socio-ecological interaction; however, it is driven by a process within the Anthroposphere – consumption.

2.3 ANTHROPOGENIC METABOLISM: CIRCULATION, TRANSFORMATION, AND CONSUMPTION

Sometimes, natural resources are used immediately after appropriation, but more often they are iteratively transported and processed on a complex pathway toward consumption. The movement of resources or transformed goods is called *circulation* and it is this process that inaugurates economic exchange. *Transformation* involves all changes to natural resources, ranging from simple operations such as food preparation to complex technological processes such as petrochemistry. *Consumption* is the process that allocates, based on the socially and historically determined human needs, those materials and energies yielded by appropriation, circulation, and transformation. It is important to recognize that appropriate, circulation, and transformation processes typically involve consumption. Although consumption follows appropriation in strict temporal terms, it is the demand generated by consumption that creates the markets driving appropriation. (Molina and Toledo 2014)

Since resource flow as cycles, understanding patterns of energy usage and material availability is an essential component of designing metabolism. To understand these patterns, it is helpful to classify consumption based on Georgescu-Roegen's (1971) biophysical interpretation of the economy, which built off the work of Lotka's (1956) endosomatic and exosomatic (Molina and Toledo 2014). In biological terms, the former refers to energy within a biological body while the latter is energy external to it. Applied to social metabolism, *endosomatic* is the bio- and geo-metabolic energy processed within a biological or planetary organism, respectively. E*xosomatics* are the techno-metabolism resulting from mechanical and chemical transformation within the socio-metabolic process. For example, a crop has embedded energy that can be transferred to humans through digestion (endosomatic), but that same crop can be chemically converted into a biofuel (exosomatic). Each case has a different *exergy*, or quantity of usable energy, and the two differ in their capacity to process energy – biological organisms have genetic limits on energy processing (Molina and Toledo 2014). This prevents direct endosomatic consumption of fossil fuels or other sources with high energy density, necessitating intermediate exosomatic processes. Thus, the significant increase in material and energy throughput is highly dependent on exosomatic processes. That these processes rely heavily on non-renewable resources stands as a significant risk to future societies. Planetary endosomatics is a new concept and therefore requires further explanation. Just as biological processes such as blood circulation and respiration empower an organism, so too do planetary processes such as atmospheric circulation and solar radiation. The scales differ greatly but both biological and planetary endosomatic requires planners to have a heightened consciousness of natural systems. Unlike that dependent on the biological variety, planetary endosomatic consumption requires an exosomatic construction to harvest or store energy. But unlike pure exosomatic production, aligning with Earth processes allows for renewable appropriation and thus greater long-term production. The complexity and underlying characteristics of anthropogenic circulation, transformation, and consumption drive energy and material requirements for both modes of social-ecological exchange, and are thus of critical importance to future-oriented social metabolic designs.

2.4 EXCRETION AND THE STRATEGIC ROLE OF ENTROPY

The conservation of mass implies that all consumed resources eventually flow back to into nature, necessitating waste handling processes. As discussed earlier, *excretion* is the disposal of materials and energy towards nature and can be in the form of solid or liquid waste, gas emissions, chemical substances, and heat (Molina and Toledo 2014). Excretion follows four social-metabolic pathways: Re-use, Recycling, Dissipation, and Pollution.

As the outputting mode of exchange, excretion is a key process in establishing long-term ecological productivity, particularly for societies with high material throughput. *Re-use*, when excreted resources are circulated to secondary transformation or consumption, enlarges the resource base by allowing for the same resources to be used twice or more. This often, but not necessarily, occurs when the secondary demand has lower energy and material requirements than does the output from the primary use. For example, water from hand-washing can be used to flush toilets. The mainstream term "recycling" is then considered re-use because resources are recirculated from primary to secondary uses within the Anthroposphere; however, materials tend to degrade as they progress through re-use cycles, often requiring energy intensive processes to perpetuate within the Anthroposphere. Re-use occurs on a variety of scales and has grown into a global phenomenon. While re-use strives to retain materials within the Anthroposphere, social-metabolic *recycling* is the process of reintegrating waste flows back into natural ecosystem production. Composting is a common example where the nutrients contained in organic waste are recycled back to the biosphere.

If the quantity or quality of recycled resources exceeds the capacity of an ecosystem's regulating and supporting services, the excretion pathway alters from recycling to the pollution. Pollution is inevitable given the current Social Metabolic paradigm; more carbon, nitrogen, sulfur, and phosphorous are mined from the Lithosphere than would be present within natural planetary cycles (Ayers 1994 cited in Fischer-Kowalski and Haber 1998). Some of these flows exceed global limits (Rockström et al 2009) including significant impacts on climatic regulation ecosystem services, otherwise known as *Climate Change*. Excreted pollution is similar to that occurring during appropriation in that it undermines ecosystem services, but it is also more likely to contain *toxic* substances foreign to natural systems that are generated during transformation. There are no ecosystem services capable of purifying or processing toxins so they have a cumulative impact on the environment, often *bio-accumulating* within the bodies of biological organisms. This trend endangers the planetary biosphere because background levels of toxicity persist for long durations, threatening the life of any organism lacking genetic resistance to toxins. The fourth excretion pathway, *dissipation*, also undermines future ecological production by distributing resources in such a way as to make their recovery unfeasible. Failure to recycle resources will, over time, degrade renewable resource bases, likely reducing the Earth's carrying capacity. The spatial distribution of natural resources, including those recycled back to Nature, is crucial because appropriation is less energy-intensive when resources are concentrated (Georgescu-Roegen 1971). Therefore, *entropy,* or the distribution and organization of resources, is a phenomenon of strategic importance to any social metabolism primarily based on renewable resources. Technological advances have the potential to increase the recoverability of resources; however, dissipation remains an inefficient and risky process due to the uncertainty of technological innovation. As the four pathways demonstrate, designing excretion is a critical aspect of developing a social metabolism based on renewable appropriation.

2.5 Geddes' Technics as a Typology of Social Metabolic Models

Social metabolism is a complex process with countless permutations, but it is important to consider recurring patterns of appropriation, circulation, transformation, consumption, and excretion. Though social metabolism is currently experiencing a renaissance, Patrick Geddes' century-old theory of Technics remains the most capable approach to categorizing social metabolic life-cycles (Figure 3). Geddes Technics are prescient and complex concepts involving both socio-ecological processes and socio-political patterns (or Civics as he called them). For example, his paleotechnics combines dissipative resource with greed and war into a unified human mode of existence (Young 2013). Much of Geddes' writings emphasize the social outcomes associated with the different Technics, but this paper focusses only on elaborating the social-metabolic processes embodied within Geddes' theory.

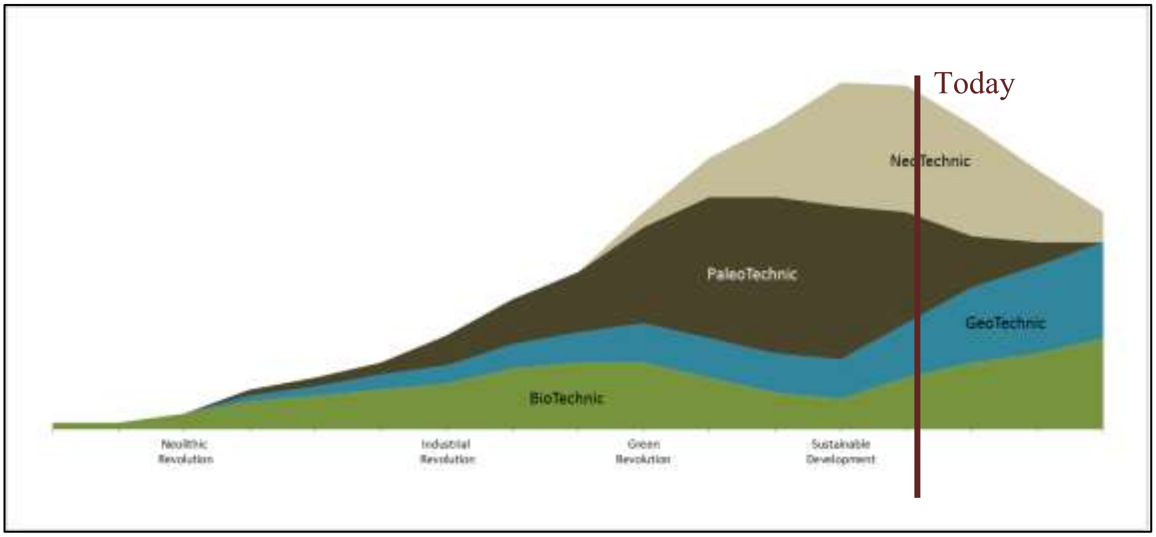

Figure 3: The History of Social Metabolism by Technic.

Geddes' four Technics provide a typology of social metabolic lifecycles. The graph above plots each over time. There are no units for the vertical axis because no measure exists that can make comparable all social-ecological effects. There is significant interaction between the four that evolves with humanity. Each of the Technics can be defined as human development that:

- *Biotechnic* (green) – leverages biological evolution to endosomatically produces goods and services
- *Geotechnic* (blue) – aligns with planetary endosomatics (wind, solar radiation, water flow, geothermal)
- *Paleotechnic* (brown) – produces exosomatically with low exergy and high impact on ecosystems
- *Neotechnic* (grey) – produces exosomatically with high exergy and minimal impact on ecosystems

It is tempting to describe each of the four Technics as a linear progression, but it is the arrangement between the technics and the commensurate social-ecological impacts that evolve. More than 10,000 year ago, humans lived as hunter-gatherers, relying mainly on a biotechnic metabolism. After the Neolithic Revolution, rudimentary paleotechnic tools enabled agriculture, increasing endosomatic crop production. Further, basic geotechnics emerged with the advent of irrigation and simple water or windmills. Improvements in sailing, a geotechnic technology that leverages atmospheric circulation, led to globalization, colonization, and increased paleotechnic resource extraction. The emergence of mechanical utilization of fossil fuels initiated the Industrial Revolution. This new industrial energy paradigm saw the expansion of biotechnic agriculture due to more sophisticated methods, tools, and transport. Concurrently, sailing was replaced by paleotechnic steam power, and increases in irrigation and water-powered manufacturing. The development of internal combustion is emblematic of a wider transition from paleo- to neotechnics, though it is hard to draw a distinct line between the two. It is difficult to delineate exactly when something is "efficient" versus "inefficient", and such differentiation would evolve over time as new technological norms take root. However, the transition from paleo- to neotechnics can be characterized by increasing exergy and decreasing environmental damage. From a modern perspective the internal combustion exhibits paleotechnic tendencies, but it was a significant advance over steam engines that inefficiently consumed vast quantities of wood and ignited countless forest fires (Rutkow 2013).

The invention of the Haber process and synthetic chemicals led to the Green Revolution, which is a highly productive but energy intensive and environmentally damaging mode of appropriation. Such increases in paleotechnics led to the negative social feedback characterized by Rachael Carson's *Silent Spring*, igniting elevated consciousness of social metabolism, eventually leading to the Brundtland Commission and the Sustainable Development movement. This movement is highly critical of the negative feedbacks associated with paleotechnics, resulting in investment toward renewable energy and the development of the ecosystems services concept, building momentum towards a social metabolism reliant mostly on geo- and bio-technics. Today, a significant paleotechnic metabolism remains, but US investment in coal has virtually ceased, energy efficiency is a professional field, and green infrastructure is becoming main stream. Current standards of living remain dependent on extraordinarily high material and energy throughput, and it is likely that transitioning towards a more viable social metabolism would require a reduction in overall throughput. However, people are learning to live high quality lives while consuming less.

One scholar has recommended that the exo-to-endo ratio, or in these terms the combined paleo- and neo- to the combined bio- and geotechnic ratio, can be used as an indicator of the level of material complexity and social evolution of society (Giampietro 2004 cited in Molina and Toledo 2014). This is true only through the emergence of sustainable development because it underestimates the potential for bio- and geotechnics to provide a high quality of life. For example, an automobile-oriented city exhibits a high exo-to-endo ratio, but a denser city designed to accommodate pedestrians, bicycles, and public transit provides a similar (or some might argue much higher) quality of life with a smaller overall metabolism. The same could be said for New York's green infrastructure approach to water quality, rain water harvesting, or a variety of other increasingly common planning interventions. Increased material and water re-use constitute significant opportunities for neotechnic development since society will eventually become dependent on renewable resources and perpetually re-used materials (metals in particular). This is the future of social metabolism, one that requires planners to leverage dynamic data systems catered towards neo-, geo-, and biotechnic development.

Though it is not the focus of this paper, social organization plays an integral role in metabolism. Geddes was keen to point out that progress made advancing the Technics of society needs to be accompanied by a concurrent development in Civics (Young 2013). A similar sentiment has been echoed by several scholars since, including Garrett Hardin's (1968) well known *The Tragedy of the Commons.* Hardin points out that some problems do not stem from technological failures or shortcoming. Rather, they result from the failure of communities to organize in such a way as to avoid and or solve the problem. Hardin uses the example of overgrazing on a communal pasture, but the acceleration of global human metabolism yields many equivalents – climate change, water shortages, soil erosion, etc. A narrow lens focused on flows is clearly insufficient, but understanding flows is essential step towards building a more comprehensive solution. The goal of this paper is to demonstrate how planners, a field with a heavy emphasis on social organization, can use social metabolism to identify and prioritize challenges facing their communities.

Chapter 3: The Evolution of Social Metabolism as Theory and Methodology

While the theoretical foundation for metabolism studies dates back to the nineteenth century, a new research tradition emerged in the late 1960s with a renewed focus on environmental impacts associated with social metabolism. Beginning in the 90s, improved computational ability allowed such studies to achieve a new level of methodological sophistication and there are now dozens (if not hundreds) of individual metabolism studies. These studies come from different research paradigms. Some focus on socioeconomic systems while others emphasize ecosystems and feedbacks. The scale of the studies range from global to functional and economic units (including cities), covering a wide array of metabolic flows (e.g. water, energy, metals, etc). (Fischer-Kowalski and Hüttler 1998)

3.1 Theoretical Foundations

Today, it is difficult to appreciate how the revolutions in life sciences affected 19th century scholars, but Molina and Toledo (2014, p.44) capture the sentiment well:

> Unlike what is seen in current specialization and partition of scientific knowledge, that frequently impedes an integrative vision, during the nineteenth century there was reciprocity in the interests of naturalists and social scholars of the time, and a genuine desire—rare in present times—for discovering universal patterns, principles, and laws that applied to all orders of matter organization.

It is perhaps unfair, given the volume of literature, to expect modern scholars to be so well versed in other fields, but social metabolism emerged as an integrative concept built by social scientists who were well read in the emerging life sciences (Molina and Toledo 2014).

Marx and Engels were among the first to do so (Fischer-Kowalski 1998). For Marx, "labour is, first of all, a process between man and nature, a process by which man, through his own actions, mediates, regulates, and controls the metabolism between himself and nature" (Marx 1970, pp. 283; cited in Swyngedouw 2006). The concept of metabolism, or *stoffwechsel*, was central to Marx theory. His use of it was more than metaphorical, he referred to a relationship of material exchange between man and nature built on interdependence instead of utilization (Fischer-Kowalski 1998). Marx was building off the works of Jacob Moleschott and Justin von Leibig, adopting the phrase "metabolic rift" from the latter (Swyngedouw 2006). Marx planted the seeds of social-ecological theory, but another 19th century scholar helped create a more comprehensive approach.

Through his critique of contemporary economics, Patrick Geddes may have established the foundations for modern ecological economics. He insisted that economists should "make a distinction between a)statistics, b) the theory of exchange (which might be called pure catalytics, said Geddes) and c) studies of the material resources of a country or the conditions of life of its inhabitants" (Martinez Alier 1987, p.90). It is the separation of c) from b) that distinguishes ecological from orthodox economics (Martinez Alier 1987). Geddes theories on economics may not have been widely adopted in his time, but they did lead him to an important metabolic breakthrough – material and energy accounting. He developed an input-output table that begins with sources of energy and materials, and then tracks them through three stages of transformation: extraction, manufacture, and transport. The comparison of the final product to the initial resource calculates losses or dissipation. Such a life-cycle approach was far ahead of its time, demonstrating the value of quantitative systemization (Martinez Alier 1987). Geddes analysis, which began in 1885, appears to be the first empirical analysis of social metabolism on a macroeconomic level (Fischer-Kowalski 1998).

3.2 Pioneering Studies

It took close to a century for the analytical framework developed by Geddes to take off. Wolman's (1965) *The Metabolism of Cities* was the first city-scale metabolism study. He used national data sets to calculate inflows of fuel, food, and water and outflows of air pollution, refuse, and sewage for a hypothetical one million person US city (Figure 4). In doing so, he pioneered the operationalization of material flows for socioeconomic systems (Fischer-Kowalski 1998), even if his analysis missed important flows such as electricity, construction materials, and other durable goods (Kennedy 2011).

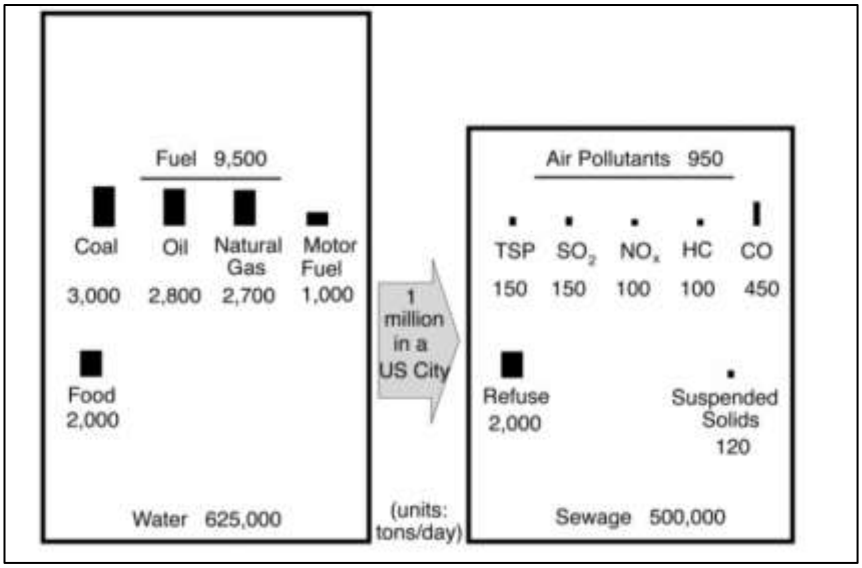

Figure 4: Wolman (1965) Urban Metabolism Analysis[3]

Soon after Wolman's seminal work, Ayers and Kneese (1969) provided a refined method through the application of the conservation of mass principle. Using a more complex model than did Wolman (Figure 5), they perform a mass balance for the entire US economy focusing on "active inputs" or materials that undergo chemical change. This excludes many large material flows such as construction material, highlighting one of the main challenges with social metabolic studies - designating system boundaries. Despite such conceptual hurdles, Ayers and Kneese produced results that stand up empirically when judged by more recent data. In doing so, they established the foundation for applied fields such as industrial ecology (Fischer-Kowalski 1998). Their analysis did exclude

[3] Source: Adapted from Wolman (1965)

nature from their mass balance, something Duvigneaud and Denayeyer-De Smet (1977) later pioneered (Figure 6)(Kennedy 2011).

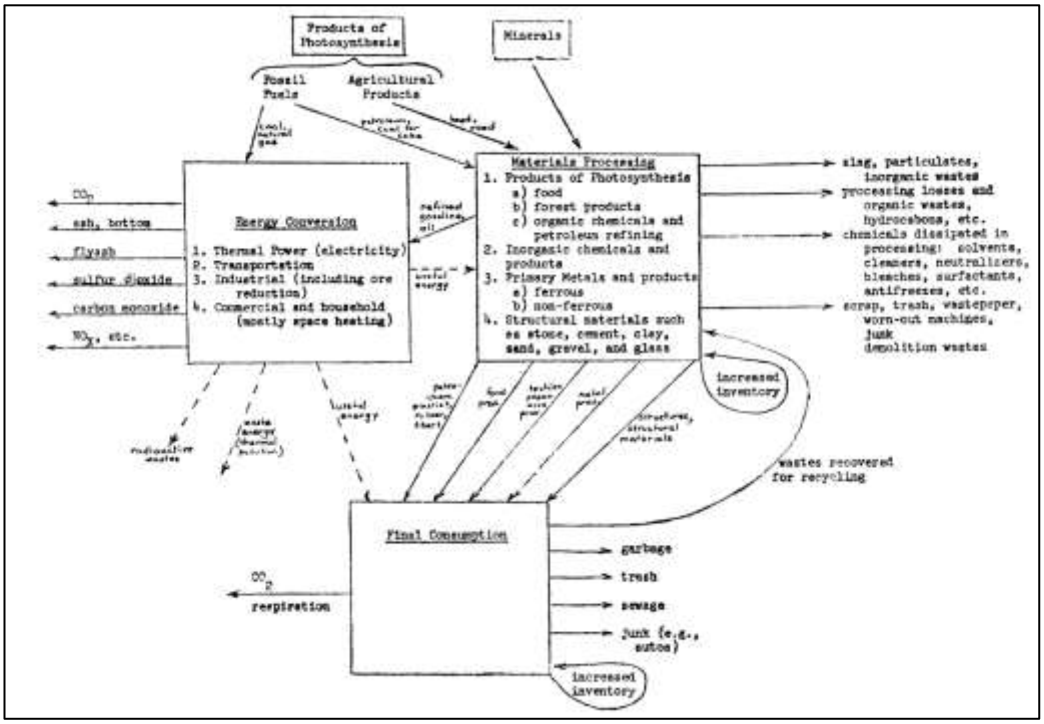

Figure 5: Material Flow Concept[4]

[4] Source: Ayers and Kneese (1969)

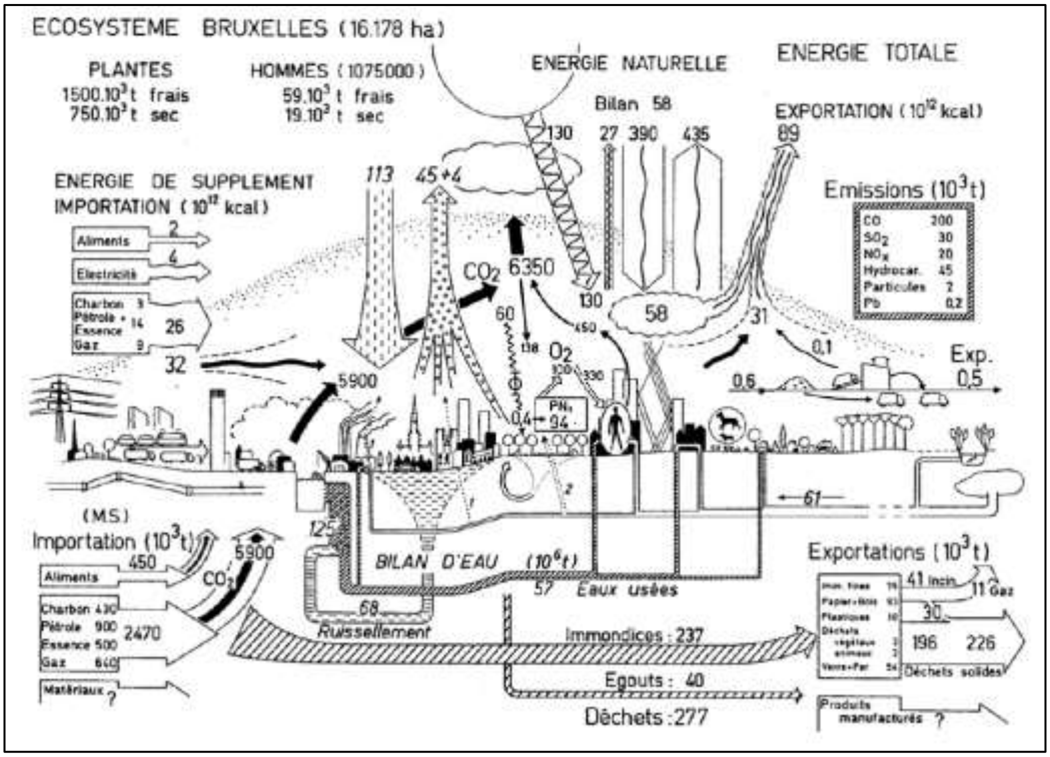

Figure 6: The Urban Metabolism of Brussels, Belgium in the Early 1970s[5]

Not all early metabolic studies focused on the flow of materials. Howard Odum (1983) developed an alternate approached based on embodied energy or *emergy*. By using a standard unit, typically solar energy, all products and services are normalized, enabling direct comparison (Song 2014, Odum 1996). While theoretically rich, Odum's emergy concept misses important chemical and physical characteristics of specific substances. For example, human diets are dependent on phosphorous, a chemical element that, unlike nitrogen, does not biologically recycle (Ayers 2007). Though Odum's emergy concept would account for the energy required to mine and process phosphorous, it

[5] Source: Duvigneaud and Denayeyer-De Smet (1977) in Kennedy (2011)

denies the importance of its non-renewability, a crucial distinction when planning for long-term metabolism.

3.3 The Proliferation of Metabolic Studies

It took more than two decades for the pioneering approaches to evolve into what is now an essential research paradigm for empirical analysis of social-ecological interaction (Fischer-Kowalski 1998). Baccini and Brunner's (1991) *Metabolism of the Anthroposphere* helped to standardize a method of metabolic analysis called Material Flow Analysis (MFA) that builds off the conservation of mass approach used by Ayers and Knees (1969). In it, the authors describe how to: define research goals and questions, delineate system boundaries in both space and time, differentiate analysis of materials versus substances, gather data and model flows as processes, and analyze and interpret model outputs. *Metabolism of the Anthroposphere* is more than a guidebook, it also quantifies the metabolism of regional socio-economic systems through analysis of four societal processes: to nourish, to clean, to reside and work, and to transport and communicate. Later, Brunner and Rechberger (2004) created an actual MFA handbook that more explicitly communicates the methodology and definitions. It also describes several evaluation methods built on MFA including but not limited to Material-Intensity per Service-Unit, Ecological Footprint, Sustainable Process Index, Life-Cycle Assessment, Exergy, Cost-Benefit Analysis, and Statistical Entropy Analysis. For a comprehensive review of MFA studies, see Fischer-Kowalski and Hüttler (1998) and Kennedy et al (2010).

Scholars have continued to improve methodology, and advances in data, communications, and computing today enables highly sophisticated studies. Walker et al (2014) leverages data from the United Nations, the British Government, energy markets, and benchmark data from previous studies to analyze the metabolic and economic effects of various resource technologies (e.g. urine capture in toilets) in London. This data is interpreted through a three-stage process starting with a sophisticated MFA model, followed by the calculation of environmental and economic performance metrics, and finally a sensitivity analysis. Cities with several million residents are incredibly complex socio-metabolic articulations. That scholars can now capture such complexity in integrated models capable of analyzing alternative futures stands as a major tool for planners and policy makers.

Not only are current studies more capable, they also come from a more diverse array of sources. China is an emerging source of advanced metabolic research. Song et al (2014) develop an emergy model with nearly 100 variables that dynamically examines the effect six alternative development policies have on urban metabolism over a 20-year period. Another Chinese study makes the breakthrough of modeling metabolism spatially. Zhang et al (2014) conduct a carbon metabolism study that maps both sequestration and emissions (Figure 7). Both of these studies demonstrate the breadth and depth of research, especially when compared with Wolman's original urban study.

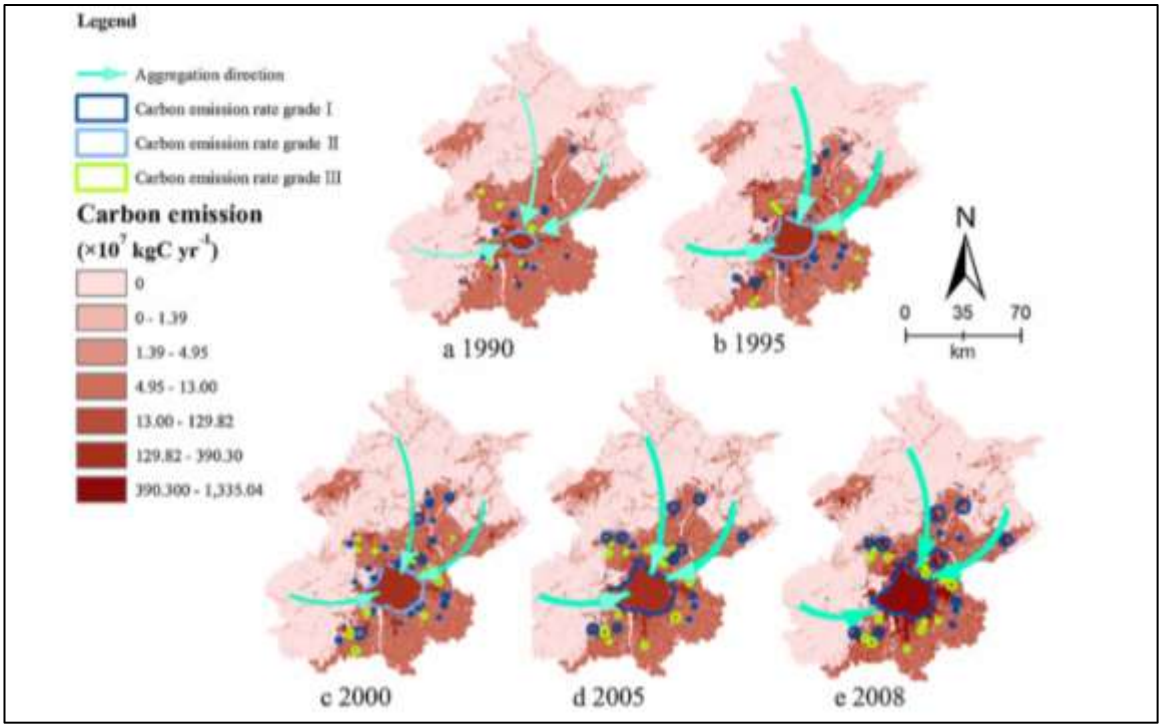

Figure 7: A Spatial Metabolic Study of Beijing between 1990 and 2008[6]

3.4 CRITIQUES

Some are critical of the dominant MFA approach to social metabolism, considering it a limited version of environmental accounting (Molina and Toledo 2014). One scholar takes the position that "cities are much more than a mechanism for processing resources and producing wastes, they are about creating human opportunity (Newman 1999, p. 222)". He proposes an "extended metabolism" model where livability is added to waste as an output of urban metabolism. By linking metabolism more directly with human well-being, Newman highlights what should be one of the main goals of

[6] Source: Zhang (2014)

social metabolism. Another major drawback of MFA is that it sees socio-economic systems as separate from natural systems. Material and Energy Flow Accounting (MEFA) (Haberl et al 2004) attempts to make explicit the feedbacks between social metabolism and the biosphere (Figure 8). Land use is particularly emphasized in MEFA and the authors point to HANPP as one tool useful in reuniting human and natural systems.

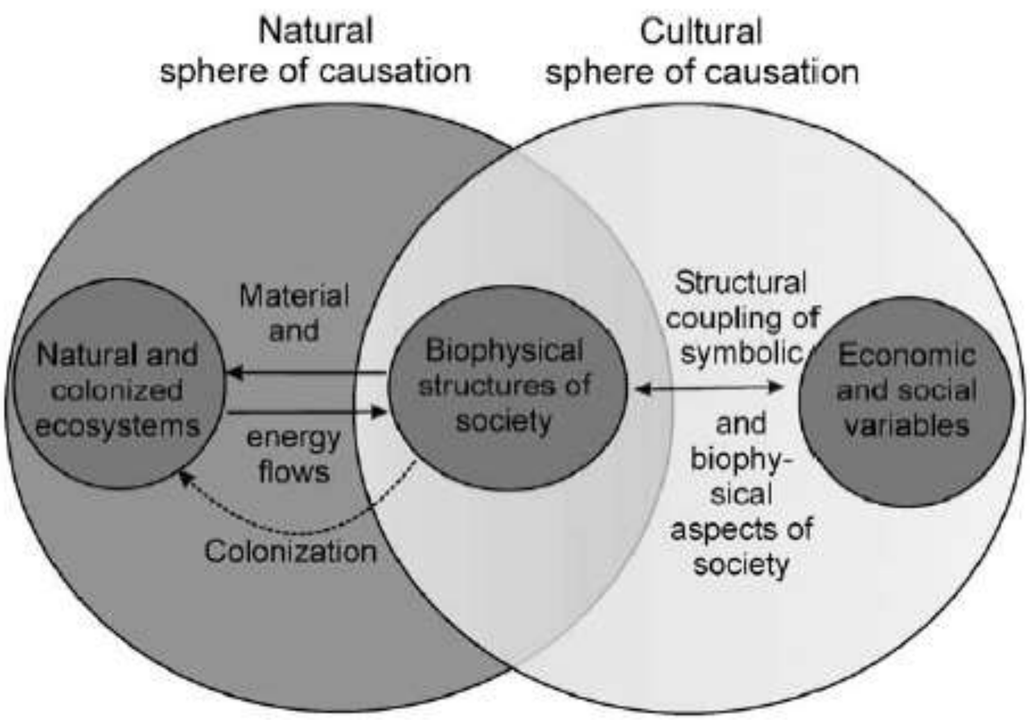

Figure 8: Social-Ecological Systems as Overlapping Spheres of Causation[7]

Social metabolic studies, whether pursued through either the MFA or emergy concept, clearly are not an all-encompassing solution to human problems; however, they

[7] Source: Haberl et al (2004)

remain an essential tool in a world where overall energy and material throughput are critically straining life support systems. To this end, Haberl et al. (2006) include socio-ecological metabolism as one of the four pillars of truly interdisciplinary research needed to address long-term ecological challenges. The other three pillars identified by the group of distinguished scholars were land use, governance, and communication. Social metabolic studies have not, to date, successfully incorporated these three disciplines, nor does its rigorous, systemic methodology lend itself to normative problem solving. The field of planning, however, already incorporates all three. Since planners are generalists trained to leverage diverse data sets, perhaps it makes more sense to integrate metabolism into planning, rather than the other way around.

Chapter 4: Precedent and Relevance for Planning as Metabolic Intervention

Even if they do not realize it, planners play a major role in shaping social metabolism. Through regulation of spatial organization, prescription of land use, and design of urban infrastructure, planning has a role in each stage of social metabolism. Urban planning emerged as a field in response to rapid growth and negative externalities from industrial development, but it evolved over time to become an inclusive process that recognizes a diversity of values and interests. It is a multidisciplinary field that, when done effectively, brings together social, environmental, and economic data to make decisions through participatory processes (Fischler 2012). The field has adapted to a changing urban and social landscape, and explicitly incorporating social metabolism is a necessary next step given the challenges facing society. This may seem a radical leap, but planning has been a metabolic field from the very beginning.

4.1 Industrialization and the Emergence of Planning

The designation of what goes where can have significant impacts on metabolism. In 1898, Ebenezer Howard (2003) developed the Garden City concept – a pattern of metropolitan urbanization with segments of countryside placed between the central city and satellite cities – to address industrial metabolic issues such as pollution and waste disposal. In MFA terms, Howard is addressing the issue of unwanted stocks. Stocks are system inputs that do not later become outputs (Baccini and Brunner's 1991). Inserting open space in between dense urban settlements enables urban-to-rural exchanges of these unwanted stocks. A contemporary of Howard, Frederick Law Olmsted (1971) also wanted to mix open space with dense urbanism, but for slightly different reasons. Instead of providing an outlet for waste, he sought to give urban dwellers an escape via public parks. Although he addressed flows of people more than materials, Olmsted's work integrated nature into cities while helping to develop awareness of pollution and other metabolic issues of the day.

Another 19th century planning scholar, Patrick Geddes, also developed methods and theory that respond to the needs of social metabolism. For Geddes, the city is a complex and reflexive entity, but he does not place town and country at odds with one another. Instead, the natural occupations found in his Valley Section reflect how landscapes constitute the foundations of an economy and culture that flow through a network of market and country towns. These flows synthesize in the city, where occupations reflect the original natural occupation, such as a baker who processes the peasant's grains. Geddes considers this coupled region-city as a "living city", a model to be replicated throughout the world, leading to a more peaceful existence with nature and within humanity (Welter 2002). In short, Geddes sees social metabolism as an integrated life-cycle that unifies cultures and societies.

4.2 Advances in the Mid-Twentieth Century

The field of planning gained momentum after the turn of the 20th century. Though much of planning focused on modernist or hygienic intervention, planning innovators continued to expand the metabolic reach of the field. In the early 20s and 30s, the Regional Planning Association of America (RPAA), which included among its membership Geddes' disciple Lewis Mumford, hoped to change what they perceived as uncontrolled and destructive growth. The RPAA transformed Howard's Garden City from a (mostly) utopian vision to an operational strategy that incorporated technologies beyond Howard's time – wide-scale electrification, communication, and the automobile (Parsons 1994). Their Regional City concept creates a regional spatial framework that, like Howard, incorporates open space and agricultural land in between polycentric urban centers. Each community would be a compact and pedestrian friendly, including trails similar to the RPAA's renown Appalachian Trail (Parsons 1994). This vision represents a stark contrast to the auto-centric Urban Field style of development (Friedmann and Miller 1965) that emerged after World War II. Despite the incorporation of the automobile, the Regional City would likely require much shorter trips, often on foot, and would generally require less gasoline and road construction materials. Unfortunately, the Regional City did not emerge as the mainstream spatial framework as intended by the RPAA. If it had, not only would modern cities be less energy and material intensive, but less open space and agricultural lands would have been displace by post-war urban growth.

It was in response to the rampant displacement of biospheric land uses that Ian McHarg (1971) developed his ecological planning method. Ecological inventories provide a baseline of data that allows planners to reconcile the impacts of urbanization on the biosphere. His method addresses the negative feedbacks associated with urbanization, making a strong case for design as an essential metabolic tool. By mitigating the externalities of growth, the order and fitness of ecosystems can be maintained, conserving productive ecosystem services. Although neither the Regional City nor Ecological

Planning immediately became mainstream planning concepts, both are integrated into current planning theory and practice.

4.3 Modern Planning As Response to Complex Metabolic Issues

Historically, planners have been good at addressing acute metabolic issues such as pollution or the displacement of open space and agriculture, but they are becoming increasingly focused on more complex metabolic issues such as energy and climate, health, ecosystem services, and macro resource availability.

Smart Growth has emerged as a mainstream planning framework in response to the climate, energy, and health issues presented by sprawling auto-centric development. While only a weak echo theoretically and operationally to the type of development proposed by the RPAA and its other predecessors, Smart Growth embraces compactness as a means of achieving resource preservation, transportation options, and community development (Ye et al 2005). In contrast with "single-use, low density land development and disconnected street networks" believed "to be positively associated with auto dependence and negatively associated with walking and transit use", the active transportation sought by Smart Growth aims to positively "affect health by influencing physical activity, obesity, and emissions of air pollutants" (Frank et al 2006, pg. 75). The framework prescribed by Smart Growth is similar to that of the compact Regional City, but it did not become widely accepted until after people realized the negative effects of the energy intense, polluting, and unhealthy Urban Field metabolism.

From Howard to the RPAA to Smart Growth, planners have demonstrated their understanding of how the spatial organization of the built environment affects metabolism, but modern planners have also come to appreciate the role nature plays in shaping the metabolism of cities. Today, Green Infrastructure (GI) is an important planning concept built off the foundation laid by Olmsted and McHarg. GI is comprised of "networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales" (Tzoulas et al 2007, pg. 169). The positive health impacts of GI are well documented (Tzoulas et al 2007), and the reintegration of ecosystem services into cities, at least partially, addresses biophysical stresses created by urbanism.

Urban development alters natural hydrological and energy exchange processes, leading to flooding and Urban Heat Island (UHI) (Gill et al 2007). Construction and development replace permeable soils with hardscape, significantly increasing runoff quantity and damaging water quality. The re-introduction of trees, rain gardens, green roofs, or other GI into urban landscapes allows rain to be intercepted, exported via evapotranspiration, or infiltrated, thus improving the urban hydrological cycle. The loss of vegetation caused by urbanization leads to reduced heat transport associated with evapotranspiration. This is exacerbated by waste heat from buildings and automobiles (Stone et al 2013), which combine to make cities warmer than surrounding rural areas or open space. Cooling cities with large UHI requires more energy and the increased heat threatens human health. In recognition of the effects of UHI, Dr. Bryan Stone (2013) suggests that cities increase forest cover in urban, suburban, and exurban locations to address these negative impacts. Doing so creates cooler microclimates (shade) and addresses the UHI macroclimate.

Urban populations have grown dramatically over the last few decades, leading to increased confrontation with the negative metabolic impacts generated by cities. Planning emerged in response to 19th century pollution and overcrowding. As cities have grown, so too have the metabolic challenges to be addressed by planners. Later, planners learned to acknowledge the importance of regional flows, both natural and anthropogenic, as crucial to human well-being. And today, the relationship between urban metabolism and global climate are well understood. Even when the phrase "metabolism" is not explicitly used, as is the case with many Smart Growth advocates, planning intervention is decidedly metabolic.

Some planners work with specific flows, such as those involved with water, energy, or waste management while others deal with comprehensive land-use and transportation planning. No matter the subject, planners have demonstrated an awareness of how urban metabolism affects city residents. Despite this pattern, the metabolic rift continues to accelerate. If human society is to meet this challenge, planners will have to be part of the solution. The next step is to move beyond implicit understanding and make metabolism one of the underlying principles of planning. To do so, social metabolism must fall within the aegis of comprehensive planning. In doing so, planners would acknowledge that local and global metabolic issues are a priority. Next, a sample metabolic study is presented followed by a discussion of how such a study informs planning.

Chapter 5: A Metabolic Planning Study of Water

Planning's approach to growth has evolved over the last 60 years. Growth has been seen as a problem to be addressed by strict regulation, but this gave way comprehensive planning methods that attempt to account for the costs of growth. This transitioned to an era of Smart Growth in which growth is seen as an opportunity to achieve desirable development outcomes. But today, this is evolving into a new perspective that attempts to balance the economic benefits derived from growth with the desire to address past development errors. (Chapin 2012)

The following metabolic planning study is therefore an example of how to achieve this most recent perspective of growth. Austin possesses the modern, accelerated, and unviable metabolism discussed in Section 1.1, but Austin's rapid growth has the potential to catalyze an evolved metabolism. Austin's contemporary water flows are a prime example of an unviable metabolism. Austin needs to develop a water metabolism that reflects the austerity imposed by limited supply and increasing demand. To accomplish this, comprehensive planning must explicitly analyze and incorporate water metabolism.

There are six attributes of comprehensive planning: the 1) presentation of the plan, 2) level of public participation used in preparing the plan, 3) fact base supporting the plan analysis, 4) infrastructure capacity analysis, 5) land suitability analysis, and 6) implementation program (Norton et al 2006). Components 3), 4) and, 5) are the most relevant to social metabolism. Traditionally, the fact base comprised of existing land use, demographics, and economic activity. Together, these drive consumption and demand. Infrastructure analysis looks at the availability, location, and capacity of existing road, water, and wastewater services. Land suitability is a practice that reflects McHarg's ecological planning, though in reality, ecological functions are not always given the highest priority.

Three changes are necessary to more fully incorporate metabolic analysis into comprehensive planning. First, the fact base must be expanded to help define the local viable metabolism. Regional context is especially important for water metabolism as dry climates demand lower metabolic throughout than do wet climates. Second, the design of infrastructure and land use strongly influence throughput, and the two should be considered an integrated function. As GI demonstrates, land use affects biophysical exchanges such as water demand and drainage. These exchanges define the required capacity for infrastructure. For example, land use with a high percentage of lawns will require substantial flows of water for irrigation, necessitating a larger water supply and distribution network. So changing land use and land management has a strong impact on infrastructure capacity. In some cases, strategically locating demand for key flows, like reclaimed water, improves the business case for supply of that flow. Reframing infrastructure is also an important step in enabling metabolic planning intervention, so the third adaptation of metabolic planning is to consider decentralized infrastructure models. Traditional planning thinks of infrastructure as large centralized facilities, but this need not be the case. For example, distributed green infrastructure can reduce the need for large centralized stormwater facilities while on-site reuse and rain catchment can greatly alter centralized water demand. The following planning study will evaluate the regional water context, analyze the land-use and infrastructure complex, and evaluate the potential for decentralized infrastructure systems.

5.1 Regional Water Context

Before analyzing the water metabolism for the City of Austin, it is essential to first understand the regional water context. Austin falls within the Colorado River basin, which begins near Lubbock in northwest Texas and flows, like most major Texan rivers, southeast toward the Gulf of Mexico (Figure 9).

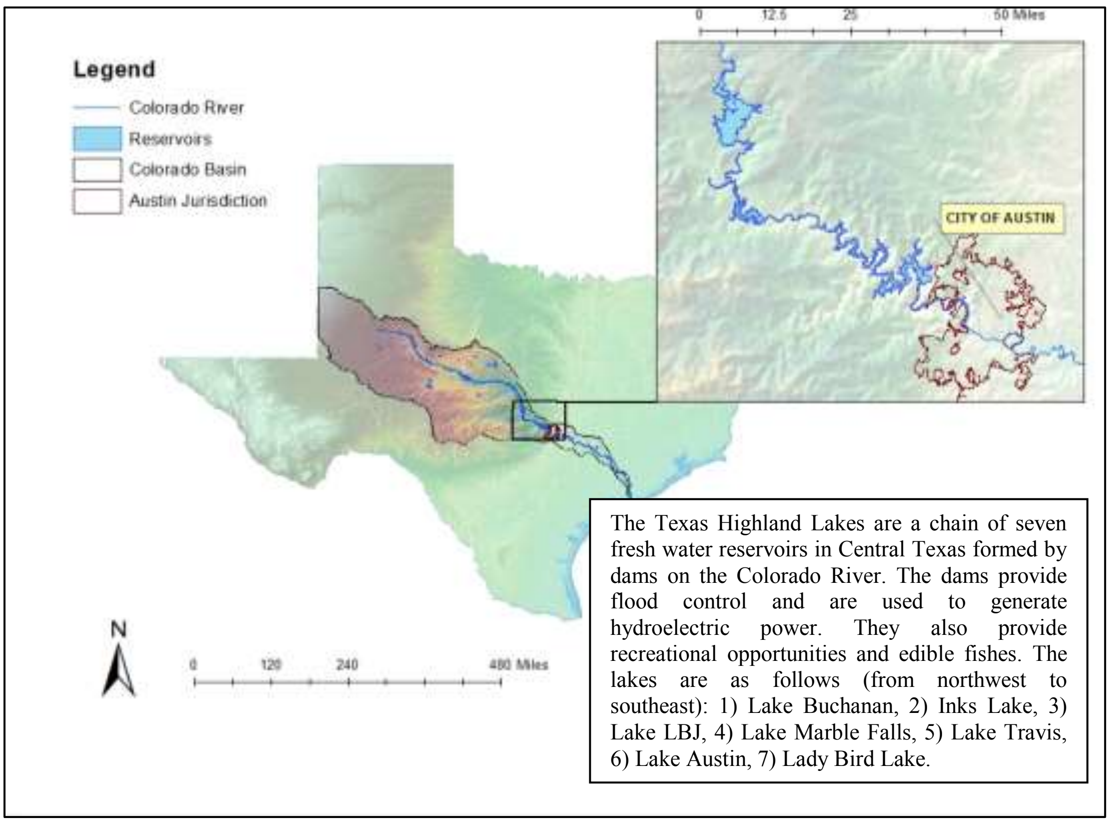

Figure 9: Colorado River Basin and Highland Lake System[8]

[8] Source: TWDB (n.d.), COA (n.d.)

The Gulf acts as a source of moisture for Texas while the mountains in the west prevent Pacific Ocean moisture from reaching Texas, creating a strong east-west precipitation gradient (Nielsen-Gammon 2011) where the eastern sections receive more than 50 inches per year while less than 20 inches fall on west Texas (Figure 10). Depending on the location within the city, Austin receives between 31 and 35 inches of rain. It should be noted that Austin is dependent on a river basin whose headwaters lie within a drier climate, and that the topography and geology upstream from Austin create high flood risk. To address water supply and flood risk (and to supply hydropower), seven dams were constructed on the Colorado River near Austin. These dams created the Highland Lakes (Figure 9), a collection of seven reservoirs that are managed by the Lower Colorado River Authority (LCRA) – Austin's wholesale water provider.

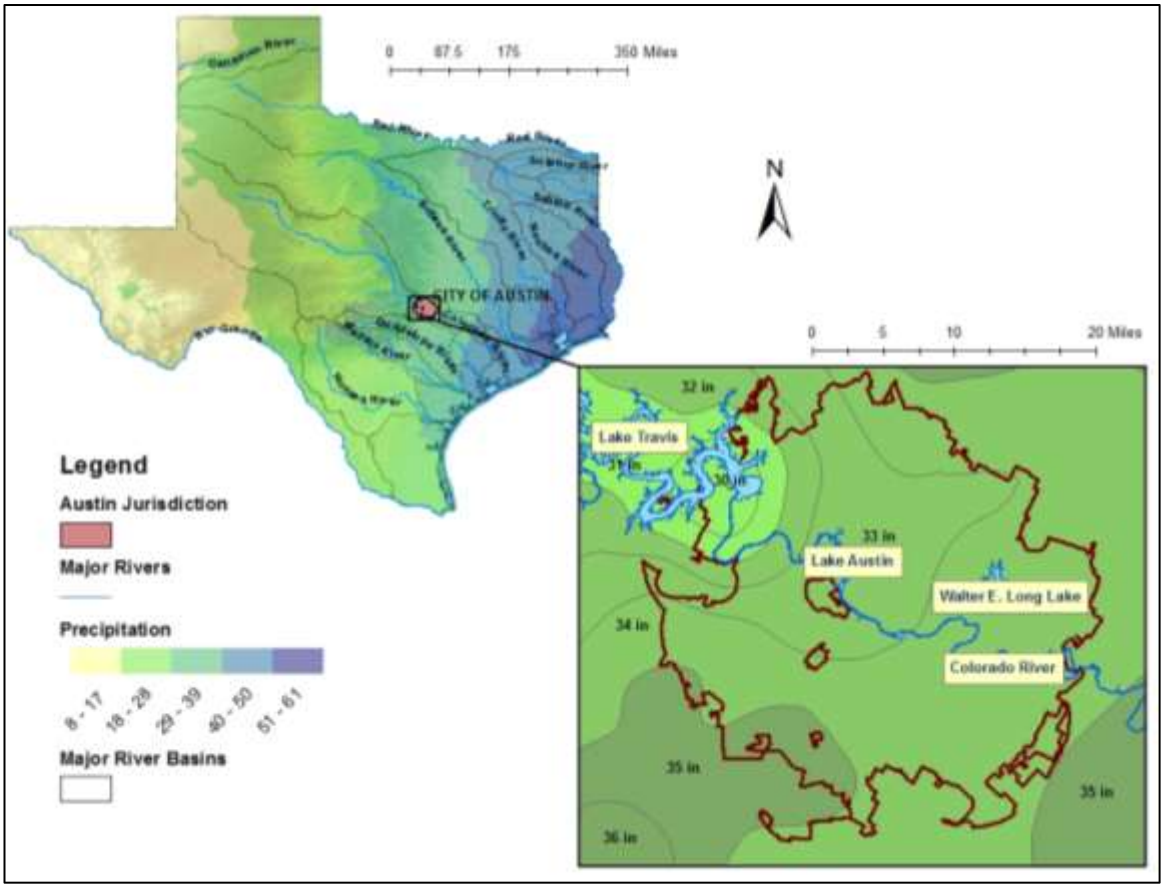

Figure 10: Regional and Local Precipitation [9]

The Highland Lakes store rain that falls during the wettest times of year – autumn and spring (Figure 11). However, this data is based on past measurement that may not accurately depict future weather patterns. Precipitation patterns, unlike temperature, are difficult to predict or model, and Climate Change only makes it more so. Some predict that Texas winters will be wetter and summers dryer, but such forecasts are uncertain. However, it is very likely that temperatures will increase, which implies higher

[9] Source: TWDB (n.d.), COA (n.d.)

evaporation and reduced water supply (Nielsen-Gammon 2011). Such changes threaten the stability of the Highland Lake system, particularly the supply of water in the driest summer months.

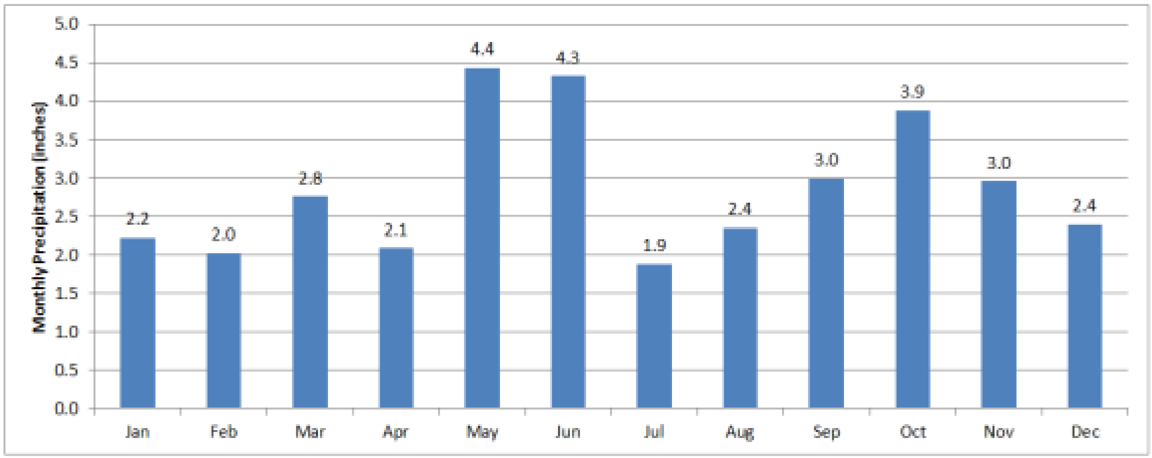

Figure 11: Monthly Precipitation Averages (1981 – 2010) at Camp Mabry; Austin, TX[10]

State government owns all surface water in Texas with the Texas Commission on Environmental Quality (TCEQ) issuing and managing water rights permits based on the "first in time, first in right" principle. Under this principle, older water rights have priority access over those that are newer. Through the "Rule of Capture", landowners own the groundwater under their land, subject to regulation by groundwater conservation districts (GCDs). GCDs permit and regulate groundwater wells, and they can be created by the state legislator, landowner petition, or TCEQ (TCEQ 2014).

Water rights can be undermined if water supply fails. The Texas Water Development Board (TWDB) was created in response to the 1950s drought of record and

[10] Source: NOAA (n.d.)

is the state agency tasked with water planning. TWDB releases a state water plan (SWP) every five years with the most recent plan published in 2012. The plan includes population and water demand projections, and identifies supply strategies. In response to a more recent drought in 2011, the state legislature created the State Water Implementation Fund for Texas (SWIFT), a $2billion loan program to fund the SWP. The legislature mandated that at least 20% of the funding must go towards conservation or reuse projects. Communities throughout Texas can submit projects to TWDB, but only those included in the SWP are eligible for SWIFT funding.

In 1997, the legislature created 16 regional planning areas (Figure 12) to facilitate a more participatory and consensus-oriented planning process. Each region creates its own plan, which is sent to the TWDB for approval and integration into the SWP (TWDB 2013). Austin falls within Region K, the Lower Colorado River, and is the largest city within the region.

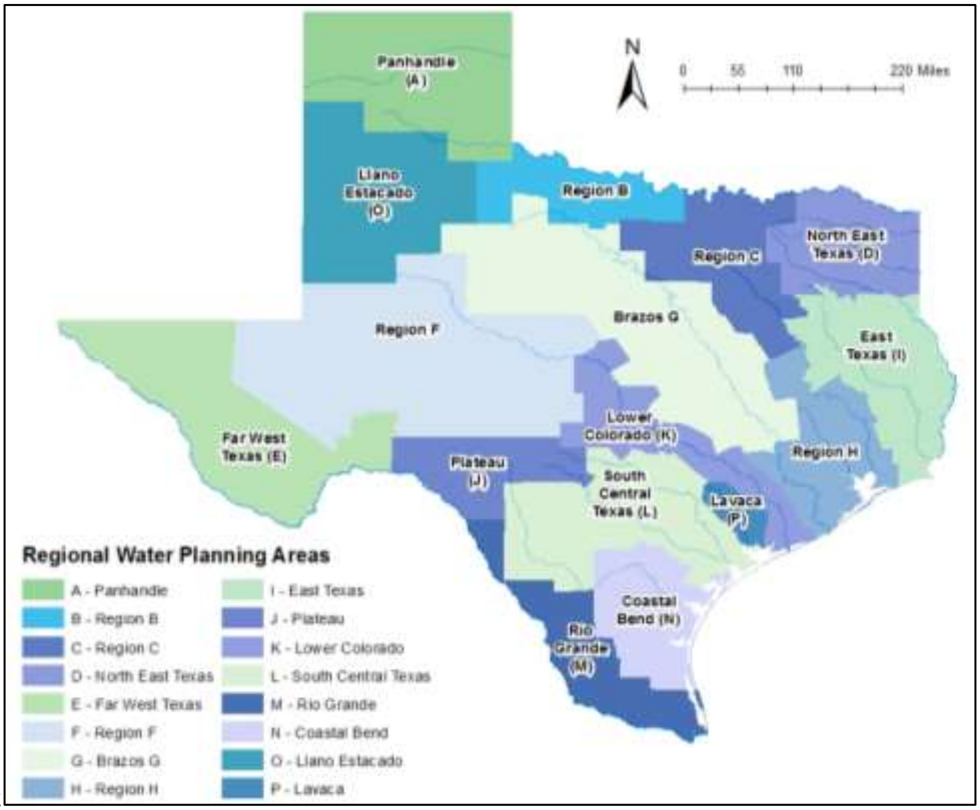

Figure 12: Texas Regional Water Planning Areas[11]

The region's population is expected to double by 2060 with a 27% expected increase of water demand (Table 2); however, the 2010 supply of 1.1million acre-feet is only expected to increase by 1% by 2060. Agricultural irrigation is currently the largest source of demand, but municipal demand is expected to surpass it by 2060. This is primarily due to population growth, though reduced irrigation demand is also a significant trend. (TWDB 2012)

[11] Source: TWDB (n.d.)

	2010	2020	2030	2040	2050	2060
Projected Population	1,412,834	1,714,282	2,008,142	2,295,627	2,580,533	2,831,937
Existing Supplies (acre-feet per year)						
Surface water	892,327	892,689	894,886	897,359	900,286	900,477
Groundwater	270,557	270,268	269,887	268,936	268,527	268,594
Total Water Supplies	**1,162,884**	**1,162,957**	**1,164,773**	**1,166,295**	**1,168,813**	**1,169,071**
Demands (acre-feet per year)						
Municipal	239,013	288,152	336,733	382,613	428,105	467,075
County-other	29,630	33,820	36,697	40,438	44,673	49,273
Manufacturing	38,162	44,916	56,233	69,264	77,374	85,698
Mining	30,620	31,252	31,613	26,964	27,304	27,598
Irrigation	589,705	567,272	545,634	524,809	504,695	468,763
Steam-electric	146,167	201,353	210,713	258,126	263,715	270,732
Livestock	13,395	13,395	13,395	13,395	13,395	13,395
Total Water Demands	**1,086,692**	**1,180,160**	**1,231,018**	**1,315,609**	**1,359,261**	**1,382,534**
Needs (acre-feet per year)						
Municipal	6,671	17,867	25,289	36,420	76,771	120,999
County-other	223	1,725	4,347	8,128	11,610	14,892
Manufacturing	146	298	452	605	741	934
Mining	13,550	13,146	12,366	6,972	5,574	5,794
Irrigation	234,738	217,011	198,717	181,070	164,084	135,822
Steam-electric	193	53,005	53,175	76,430	81,930	89,042
Livestock	188	188	188	188	188	188
Total Water Needs	**255,709**	**303,240**	**294,534**	**309,813**	**340,898**	**367,671**

Table 2: Region K Population, Water Supply, Demand, and Needs 2010-2060[12]

Region K water supply and demand do not always align. Supply and demand are calculated for each water user group (municipal, county-other, etc) where supply calculations are made based on water that is legally and physically available during a drought of record. Water needs exist when user group demand is greater than available supply. In 2010, irrigation needs constituted 92% of total needs, but 2060 forecasts show reduced irrigation needs and significantly increased municipal and steam-electric (power plant) needs (TWDB 2012). To meet current and future needs, several management strategies are proposed within the SWP (Figure 13). The most significant strategy is the Lower Colorado River Authority/San Antonio Water System project (LSWP) that

[12] Source: Adapted from TWDB (2012)

consists of off-channel reservoirs to store excess water during wetter months, agricultural water conservation, additional groundwater development, and changes to surface water rights (TWDB 2012). It is also important note that a significant portion (approximately 60%) of water diverted for municipal use is returned to the Colorado as effluent discharges. Despite increased municipal reuse, these effluent discharges are forecast to increase by 47% in 2060 (LCRWPG 2010).

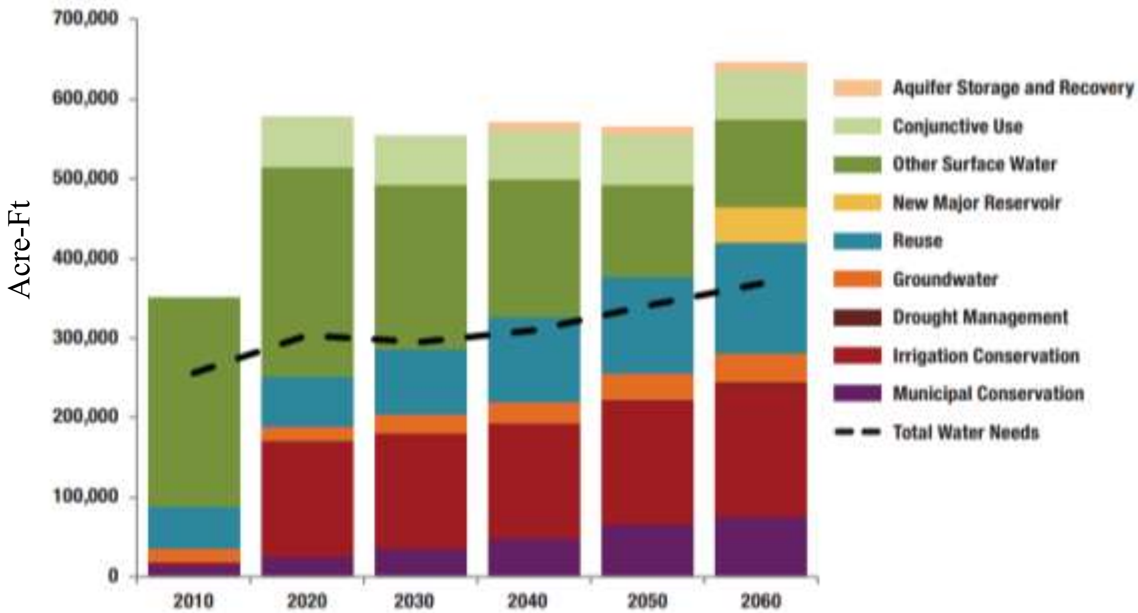

Figure 13: Region K Recommended Water Management Strategy Supply Volumes for 2010-2060[13]

In the context of rapid population growth and limited supply, water is a major concern across Texas; Austin and Region K are no exception. The LSWP, which is an integrative approach that coordinates municipal and agricultural water demands, is a

[13] Source: Adapted from TWDB (2012)

reaction to this emerging water conflict. Population growth and climate change will strain the Colorado system and, though the SWP identifies sufficient Region K water supply strategies through 2060, uncertainty regarding future climate and strategy implementation creates significant risk of future water shortage. Austin should therefore adopt a metabolic maximization strategy that prioritizes re-use, conservation, and rain catchment.

5.2 City of Austin Water and Land Use

The City of Austin (COA), through its own water rights and a water-supply agreement with the LCRA, has a legal water supply up to 325,000 acre-feet per year (COA and LCRA, 1999). Another agreement in 2007 created the COA-LCRA Water Partnership (Water Partnership), a cooperative water management structure tasked with planning an additional 250,000 acre-feet per year. It has yet to be determined if future water supply will be able to satisfy such a high, rapidly growing demand (Figure 14).

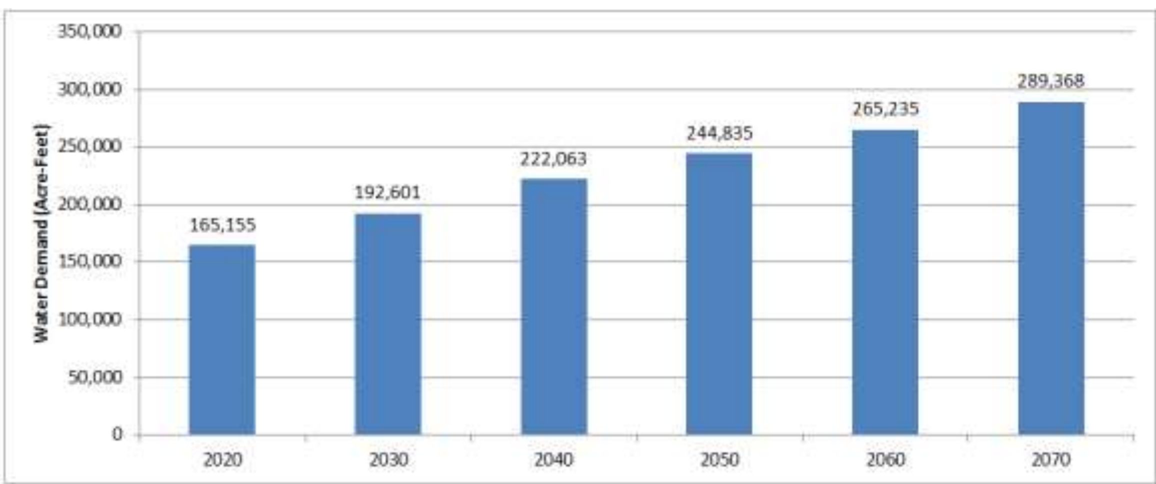

Figure 14: Austin, TX Municipal Water Demand Projections for 2020-2070[14]

[14] Source: TWDB (2015)

Austin's municipal water system begins with three main water treatment plants (WTPs) on the western (upstream) portion of the city (Figure 15). Over 139 acre-feet are treated between the three WTPs (Figure 16, Table 3). After treatment, water is piped from the WTPs to consumers throughout the city. Of all water usage, nearly 80% goes to residential customers of which more than 50% is single family (Figure 17). Once used, water is collected and distributed through sewers to two wastewater treatment plants (WWTPs). At the WWTPs, approximately 111 acre-feet of influent (sewage) is separated into sludge and treated water (Figure 18, Table 4). The water is treated onsite and is then either discharged to the river or redistributed via "purple" pipes to consumers of reclaimed water. An average of 3.5 acre-feet per year of reclaimed water was produced in 2013 -14 (Figure 19, Table 5). The other process output, sludge, is piped to the Hornsby Bend Biosolids Plant (Hornsby Bend) where it is first treated and later composted with landscaping waste collected by COA. Approximately 40,000 cubic yards of compost is sold throughout the region as Dillo Dirt™. No water is discharged from Hornsby Bend (AW n.d.).

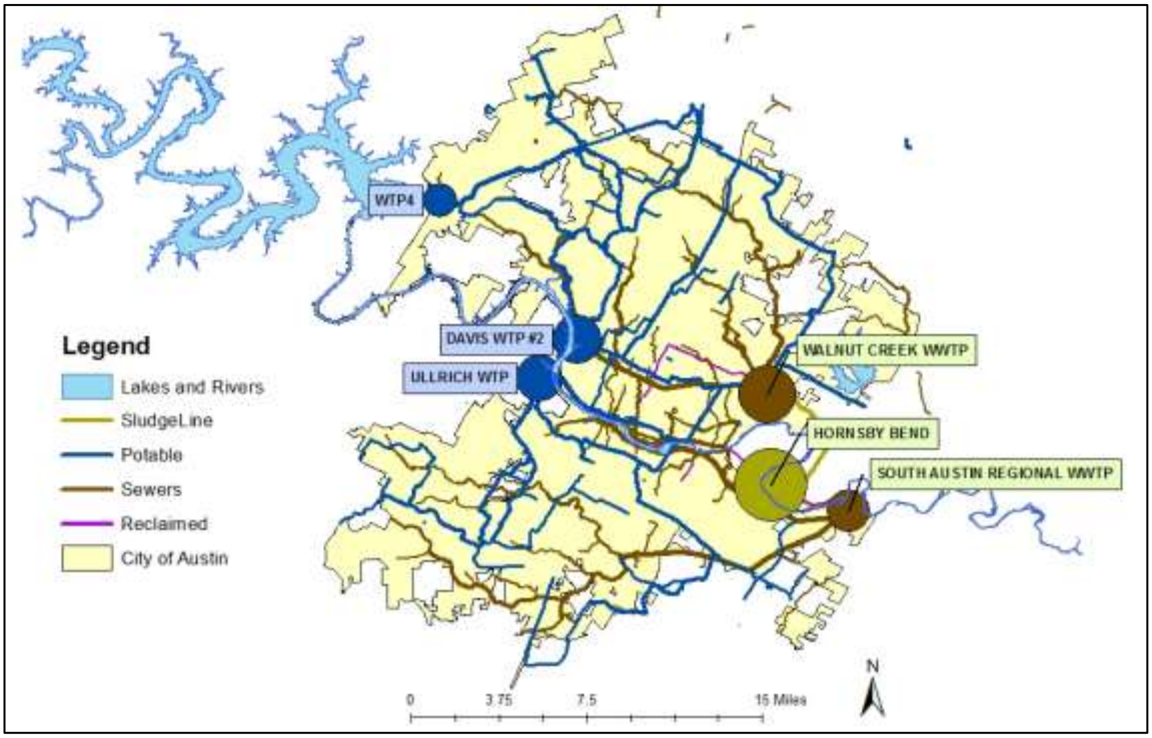

Figure 15: City of Austin Water System[15]

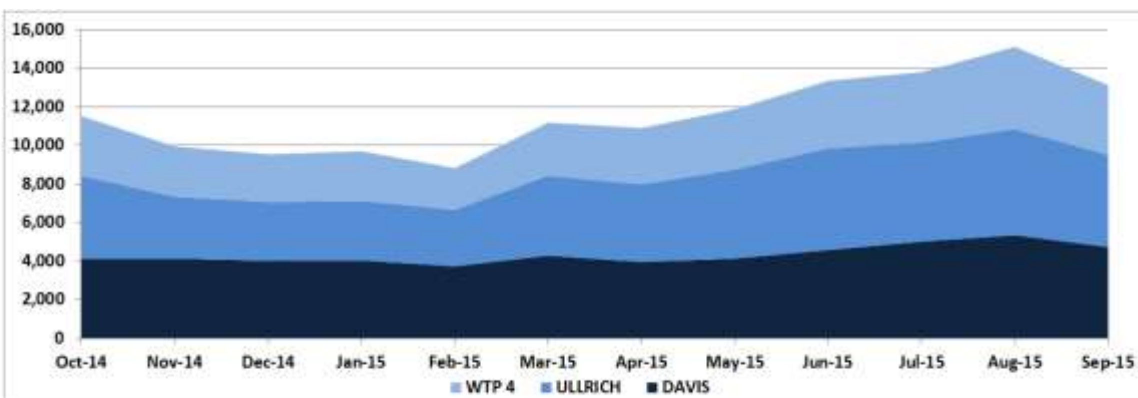

Figure 16: Water Pumped by WTP, Monthly 2014-15 (Acre-Feet)[16]

15 Source: COA (n.d), Austin Water Systems Planning (2015a)

16 Source: AW Systems Planning (2014)

	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Total
DAVIS	4,131	4,149	4,027	4,048	3,749	4,301	3,968	4,150	4,593	5,027	5,361	4,746	52,252
ULLRICH	4,303	3,204	3,059	3,095	2,928	4,139	4,023	4,619	5,269	5,136	5,499	4,777	50,050
WTP 4	3,100	2,610	2,468	2,566	2,159	2,758	2,924	3,124	3,501	3,654	4,265	3,611	36,740
SYSTEM TOTAL	11,534	9,963	9,554	9,710	8,836	11,199	10,916	11,893	13,363	13,817	15,124	13,134	139,041

Table 3: Water Pumped by WTP, Monthly 2014-15 (Acre-Ft)[17]

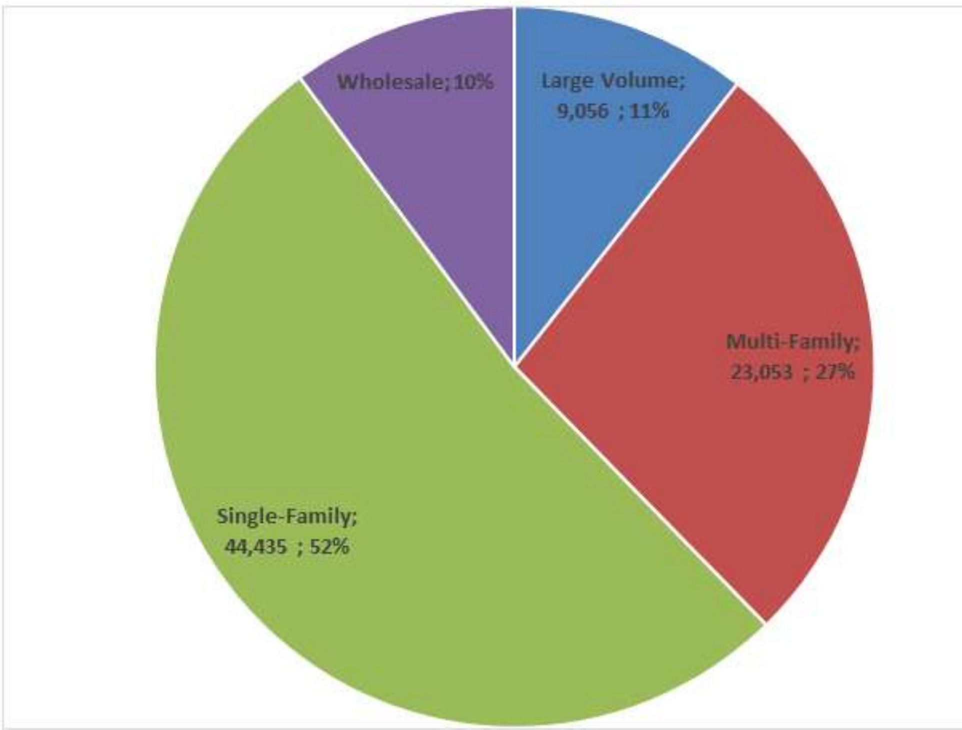

Figure 17: Water Usage by Customer Class in 2012[18]

[17] Source: AW Systems Planning (2014)
[18] Source: data.austintexas.gov (n.d.)

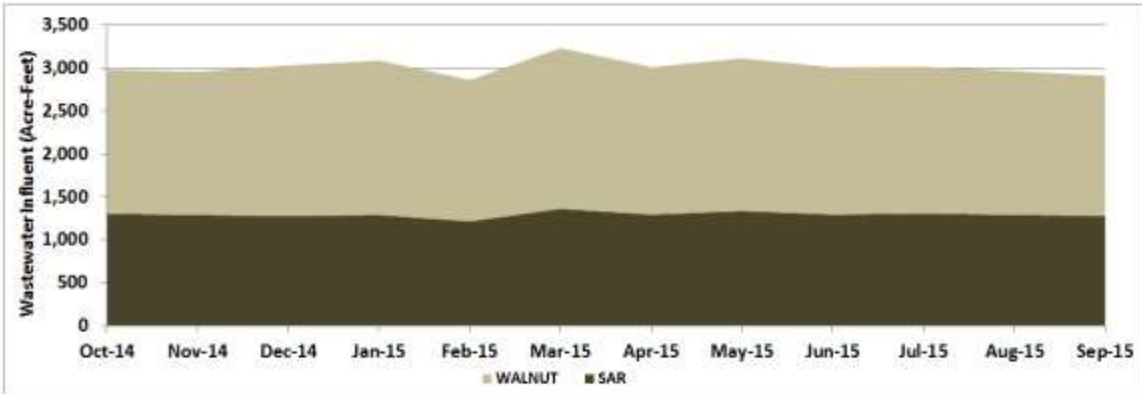

Figure 18: Influent Treated by WWTP, Monthly 2014-15[19]

	Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Total
SAR	4,010	3,964	3,924	3,963	3,734	4,183	3,978	4,104	3,978	4,017	3,968	3,930	47,754
WALNUT	5,145	5,121	5,384	5,517	5,053	5,745	5,269	5,455	5,263	5,245	5,135	5,004	63,336
SYSTEM TOTAL	9,155	9,085	9,308	9,480	8,787	9,929	9,247	9,559	9,241	9,262	9,103	8,934	111,090

Table 4: Influent Treated by WTP, Monthly 2014-15 (Acre-Ft)[20]

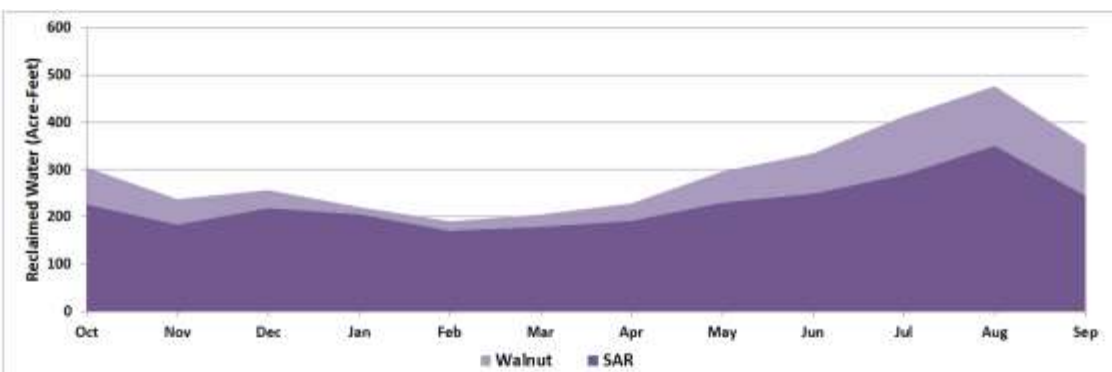

Figure 19: Reclaimed Water Volumes by WWTP, Monthly Averages for 2013-14[21]

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[19] Source: AW Systems Planning (2014)
[20] Source: AW Systems Planning (2014)
[21] Source: AW Systems Planning (2015b)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
SAR	227	184	219	206	171	180	193	231	250	290	351	245	2,749
Walnut	78	53	38	15	20	25	36	65	85	123	125	107	771
System Total	305	238	257	221	191	205	229	296	336	413	477	353	3,519

Table 5: Reclaimed Water Volumes by WWTP, Monthly Averages for 2013-14 (Acre-Ft)[22]

5.3 Distributed Infrastructure Potential

The City of Austin, like most cities, invests heavily into large, centralized infrastructure systems; however, decentralized or distributed infrastructure can also contribute to the city's metabolism. Each stage of the water metabolism – supply, re-use, and disposal – can be decentralized.

In addition to the 139 acre-feet pumped by the three WTPs, 486 acre-feet of rain fall on Austin each year (COA n.d., TWDB n.d.). Not all of this can (or should) be harvested, but there remains a significant opportunity to augment surface water supplies. There are several methods for calculating rainwater catchment (Belmeziti et al 2013, Liaw and Chiang 2014, Ghisi et al 2006), many of which involve stochastic modeling of precipitation patterns, storage capacity, and onsite demand. Due to technical and time considerations, this study will assume a simple aggregation method. In theory, each square foot of collection surface catches .62 gallons per inch of rainfall, but it best to assume that 10% to 25% will be lost to inefficiencies due to first flush requirements, excess during heavy storms, splash-out, etc (TWDB 2005). Therefore, this paper will use a conservative .46 gallons per square foot per inch of rain constant (this assumes 25%

[22] Source: AW Systems Planning (2015b)

loss). Applying this constant to the building footprints across the city yields a rainwater harvesting potential of over 30,000 acre-feet or 22% of current supply (COA n.d., TWDB n.d.). Obviously, much of this will not be feasible from a technical or economic perspective, but it does demonstrate that rainwater can potentially make significant contributions to Austin's water metabolism.

Supply is not the only form of decentralization. On-site reuse is an important strategy for maximizing existing supply. Greywater, which includes all household water outputs except the water flushed down the toilet or irrigated, is an abundant source of re-usable water. A 2.6 person household can produce from 40 to 90 gallons per day of this water greywater (Austin Water 2013). The characteristics of this greywater, such as pH or dissolved solids, vary depending on the source (ie. laundry water is different than that used to wash one's hands). And to reuse greywater, it must satisfy requirements for hygienic safety, aesthetics, environmental tolerance and economic feasibility. The specific requirements depend on whether the end-use is potable or not (Li et al, 2009) as well as local regulations. Given these complexities, it is difficult to provide an exact analysis of the metabolic potential for greywater. However, rough approximation can hint at possible significance. The population of Austin is close to 900,000 people. Using the greywater estimates from Austin Water, there is between 15,000 and 35,000 acre-feet of greywater are available to be reused, potentially contributing between 11% and 25% of COA water, respectively. Reaching these levels is likely unfeasible, it does demonstrate that greywater has potential to significantly increase the utilization of existing water supply.

There are also legitimate methods for the decentralization of disposal, the final stage of the water metabolism. However, onsite methods such as septic tanks or composting toilets are not as well suited to dense urban environments. While some decentralization is possible, any volume large enough to significantly affect the metabolism would also come with high risks to water quality and public health. Thus, this study will not estimate an impact for decentralized waste systems. However, similar studies conducted on rural areas should consider the benefits and avoided costs of such decentralization. It should also be mentioned that all wastewater solids are composted in Austin, and the nutrient retention benefits of decentralized systems can be acquired via Dillo Dirt.

Chapter 6: Discussion and Conclusion

Like so many issues dealt with by planners, changing metabolism involves issues of public good and equity. Policies and plans derived from city-wide analysis will inevitably affect different urban constituents differently. Thus, there may not be an objectively optimal solution to this "wicked problem" (Rittel and Webber 1973). Despite this challenge, social metabolism remains an essential theory and source of data for planners. Metabolic analysis provides critical information necessary for establishing place-based planning values. For Austin, such analysis points to a value system that prioritizes and cherishes water. The following analysis will use data presented in Chapter 5 to present several methods of realizing a more viable water metabolism. It is not the intention of this paper to identify which is optimal. Doing so requires discussion amongst a wide range of stakeholders that is beyond the scope of this paper. This paper aims to inform and provide options to such a discussion.

6.1 METABOLIC ANALYSIS

Despite Austin's relatively wet weather, it is dependent on water stressed sources. The two main reservoirs in the Highland Lakes, Travis and Buchanan, are both at 37% capacity (LCRA April 2015). The water levels in both are well below historical averages and close to historic lows (Figures 20 and 21). If drought conditions persist, the lakes could enter Emergency status as soon as July 2015 (LCRA April 2015). Not surprisingly, Austin has a long history of pursuing conservation efforts (Gregg et al 2007), but these did not yield much progress until more recently. In 2006, the per capita water use was 190 gallons a day. Less than a decade later, that same figure has dropped down to 125, though partly due to increased rainfall (TWRPTF 2014). Despite this marked decrease in per capita consumption, the Highland Lakes remain close to record lows. As the population continues to grow, Austin planners must therefore take action to facilitate a more viable water metabolism. Increased efficiency and diversity of supply are two key strategies moving forward.

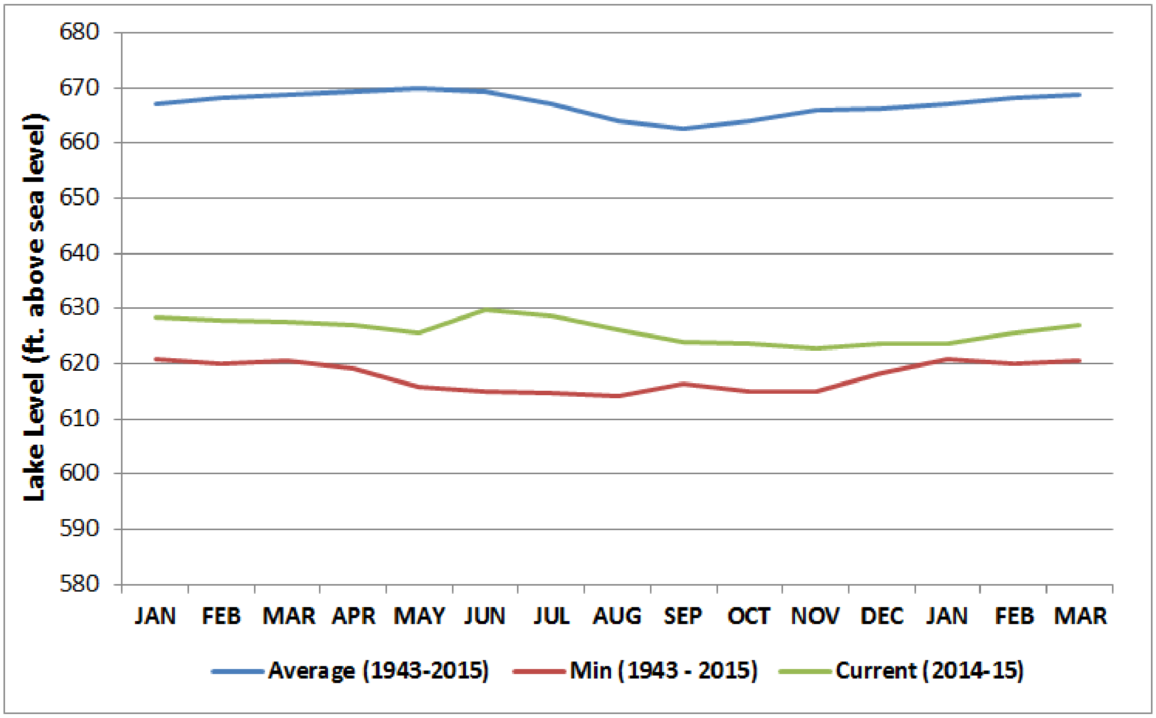

Figure 20: Lake Travis Water Levels[23]

[23] Source: LCRA March (2015)

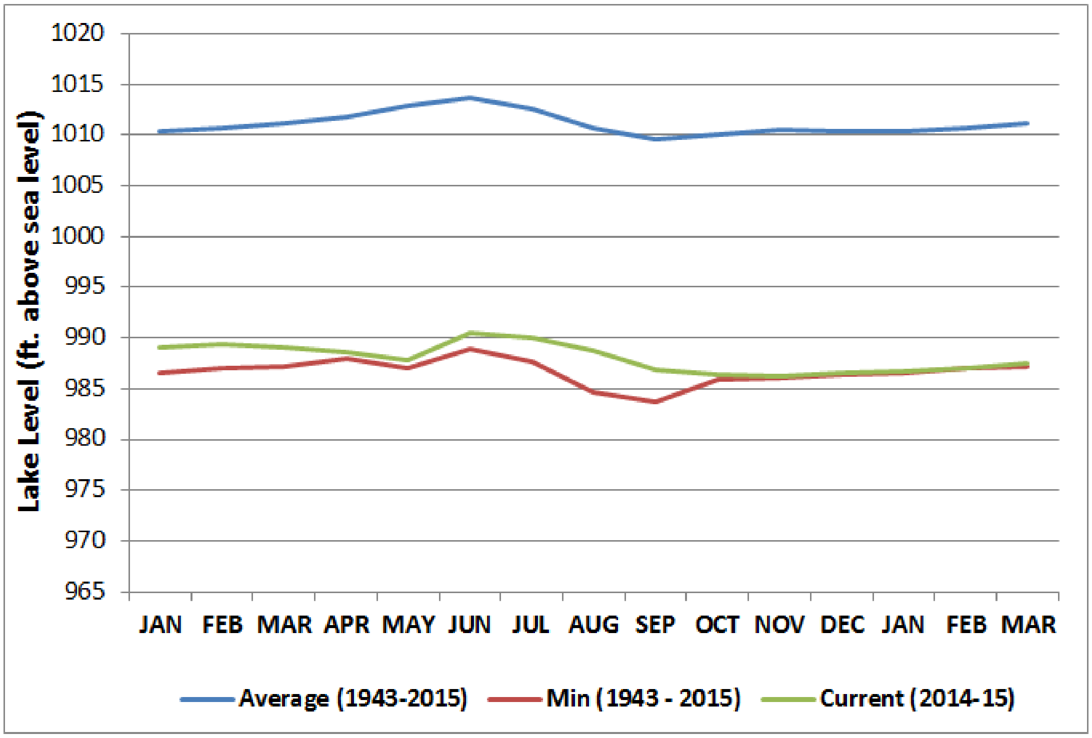

Figure 21: Lake Buchanan Water Levels[24]

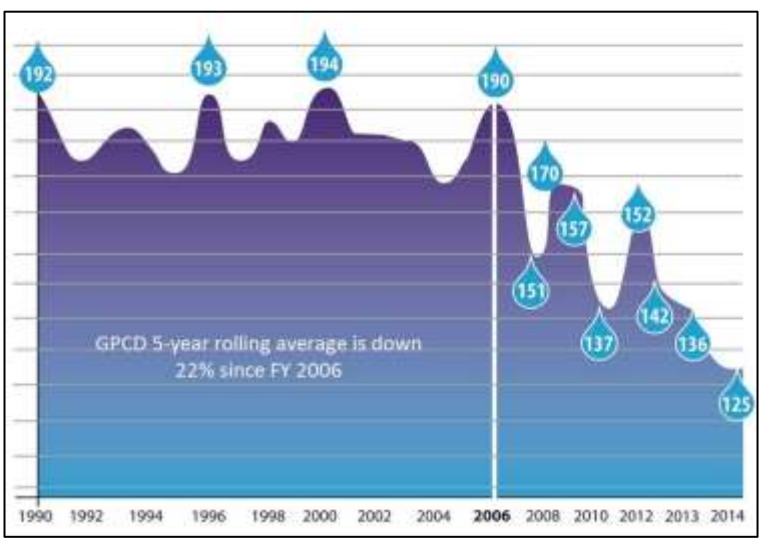

Figure 22: Austin Gallons per Capita per Day[25]

[24] Source: LCRA March (2015)

6.2 Metabolic Planning Interventions

Based on Austin's existing water metabolism, planners should promote two crucial water planning interventions. The first is increasing the demand for reclaimed water by strategically locating land uses with high potential to re-use water. Of the water treated at Austin's WWTPs, only 3% is reclaimed (Figure 23). In theory, Austin could use much more of its treated wastewater. In-stream flow requirements are the primary factor preventing 100% reuse.

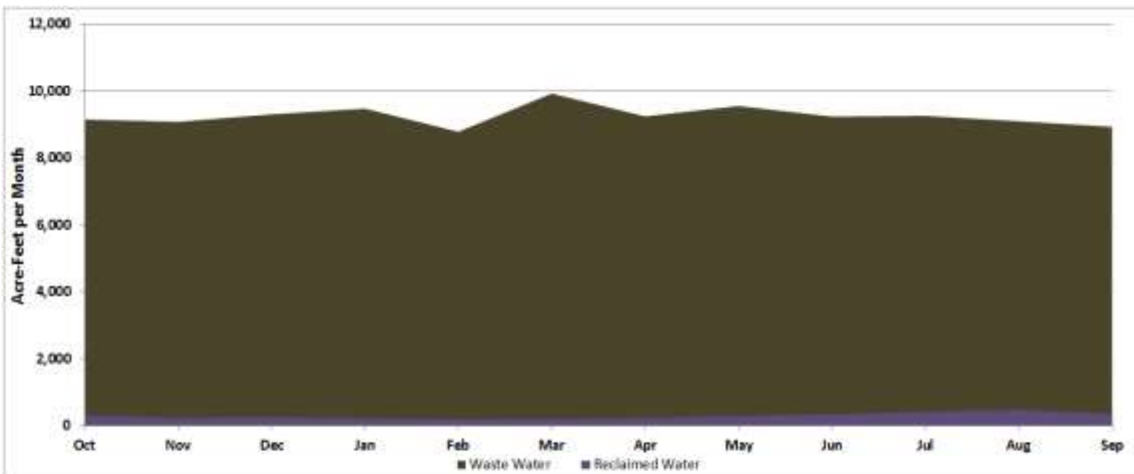

Figure 23: Wastewater Treated vs Water Reclaimed[26]

The second strategy is to promote decentralized water systems, either rainwater catchment or greywater re-use. These two interventions target different water users. Though it would be ideal for everyone to irrigate and flush toilets with reclaimed water, the capital investment in distribution and ongoing energy costs for pumping would be costly. Therefore, large users such as golf courses, cooling towers, or water-intensive

[25] Source: Austin Water (2015)

[26] Source: AW Systems Planning (2014), AW Systems Planning (2015b)

manufacturing facilities are preferred targets for reclaimed water. This means most buildings are better suited to decentralized methods. However, not all buildings are equally suited to greywater or rainwater harvesting. Retrofitting old buildings is considerably more expensive then designing the systems into new buildings. The Belo Center, a recently built structure on the University of Texas campus, catches more than 1 acre-foot of rain each year, leading to reduced water bills. The rainwater harvesting project paid for itself in less than three years. Given these resource and fiscal outcomes, most new development should be required to incorporate rainwater harvesting into building design to.

6.3 CONCLUSION

Metabolism, whether in strict biological or social-ecological terms, focusses on flows that support life. The flows that support humans have exhibited an accelerated growth that cannot be sustained. Social metabolism has emerged as an essential tool for in-depth study of these flows, but such research must proliferate among those professions that guide and shape the metabolic profile of society. Planners play a crucial role in shaping urban metabolism, and are thus one of the most important targets for social metabolic research.

The field of planning emerged in response to the negative feedbacks associated with industrial metabolism and has evolved to address more complex metabolic issues; however, it has done so in a reactive manner. Its time planners become more proactive and design the metabolism of cities. To do so, they must explicitly incorporate social metabolism into comprehensive planning, making resource conservation and utilization among their highest priorities.

To demonstrate this concept, I conducted a metabolic planning study on the water metabolism in Austin, TX. Given rapid population and an already strained regional water supply, it is clear that a viable water metabolism in Austin has to be highly efficient. Though land use, building regulation, and infrastructure strategy, planners strongly influence water metabolism. Co-location of water-intensive land use, such as golf course or cooling towers, with sources of reclaimed water ensures higher system efficiency. Supplementing this by encouraging distributed infrastructure systems, such as rainwater harvesting and greywater reuse, increases the available supply while reducing the need for energy intensive distribution and treatment systems. If implemented, these strategies would increase water supply while decreasing dependence on a water-strained region. It is not surprising that a July 2014 report by the Austin Water Resource Planning Task Force came to similar conclusions. Those professions dealing directly in metabolic flows are highly conscious of those flows. But unlike planners, these professionals have limited control over the shape of cities. Though long present as a fundamental though unacknowledged aspect of planning, the time has come for planners to proactively design the metabolism of cities.

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